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INTENSITY MEASUREMENTS ON THE COMPTON EFFECT FOR SOFT X-RAYS

By Russell H. Varian

INTRODUCTION

Jauncey's extension of the Compton-Debye theory of scattering, predicts that the ratio, R, of the intensity of the modified component to that of the unmodified component should increase with increasing scattering angle and with decreasing wave length. Experiments performed by Compton,[1] Ross,[2] Webster,[3] De Broglie and Dauvillier,[4] and others, have shown that this prediction is at least qualitatively correct. The object of the experiments here described was to determine R at various scattering angles for copper $K\alpha$ rays scattered from carbon and paraffin.

APPARATUS

The study of Compton scattering of x-rays having a wave length of about 1.5A is beset with two difficulties not encountered in such magnitude when studying the Compton effect for harder rays.

The first is that CuK rays are so readily absorbed that only a very small percentage of the rays will penetrate the glass wall of an ordinary x-ray tube. The second trouble is that due to the high absorbability of these rays only the very surface of the scatterer actually does any scattering and hence the intensity of the scattered radiation is small.

An obvious solution of the first difficulty is to use a tube with thin aluminum foil windows. The second difficulty may be surmounted by putting a large amount of power into the tube and using as much of the radiation produced as possible by placing the scatterer very close to the focal spot.

A tube was constructed embodying these ideas which worked satisfactorily with 40 ma from a synchronous rectifier at from 30 to 40 kv.[5]

[1] A. H. Compton, Phys. Rev., *22*, p. 409; 1923.
[2] P. A. Ross J.O.S.A. & R.S.I., *11*, p. 219; 1925.
[3] Webster & Ross, P.N.A.S., *11*, p. 224; 1925.
[4] De Broglie & Dauvillier, J. de Phys. et Rad., *6*, p. 369; 1925.
[5] This Journal.

Using this power input adequately exposed spectrograms of scattered Cu*K* rays were obtained in ten hours. Of the scatterers used in this work, one was made of very pure natural graphite, one of pure carbon produced from sugar, and another of paraffine.

METHODS

The ratio *R* of the modified to the unmodified component was determined by photographic densitometry. Keeping the slit in the densitometer described by Professor G. R. Harrison[6] narrower than the distance between densitometer settings, the opacity of from 25 to 35 points across the modified and unmodified lines was measured. The lines were long enough to allow three or more independent runs across each film. The energy causing the blackening was then assumed to be proportional to the density, which is the logarithm of the opacity. This relation between energy and opacity has been reported by several observers[7,8,9], and will be assumed to hold here, although some claim to have found slight departures from it.

The scattering angle was determined by equating the Compton-Debye expression for the wave-length shift to the measured shift and solving for the scattering angle.

SOURCES OF ERROR

Errors due to defects of spectrographs were guarded against by the simultaneous use of two fixed crystal spectrographs of slightly different design.

The tube was mounted vertically so that the surface of the target was horizontal, and the scatterers for the two spectrographs were placed on opposite sides of the tube. An exposure was taken and then the scatterers were interchanged, and another exposure taken. The similarity of the results obtained with the two spectrographs make errors from defects in the spectrographs seem unlikely.

The first pictures were taken using the natural graphite scattering block. *R* as determined from these pictures varied very rapidly with scattering angle, and it was thought that this might be due to regular orientation of the crystals in the graphite. However, as the charred sugar gave no consistently different results, the possibility of error due to crystal reflection in the graphite seems small.

When the fixed crystal method of spectrography is used, as in this work, every slightly different wave length recorded on the film has its

[6] G. R. Harrison, J.O.S.A. & R.S.I., *10*, p. 157; 1925.
[7] D. Glocker and W. Traub, Phys. Zeits., *22*, p. 345; 1921.
[8] W. Russe, ZS. fur Physik, *34*, p. 11; 1925.
[9] J. K. Robertson and J. T. Thwaites, Roy. Soc. Canada, Trans., *18*, Sect. *3*, p. 99; 1924.

origin in a different part of the scatterer. That is, every line on the film has a counterpart on the scatterer. Therefore, if there is any difference in the intensity of illumination of different parts of the scatterer there will be an error introduced in the value of R. As the positions from which the modified and unmodified components come are separated by only 0.2 mm, and the windows of the tube transmit a cone of rays of large angle, the only variation of intensity on the scatterer which need be considered is that due to distance from the focus. This effect would tend to raise the value of R by not more than 5%, and as this is smaller than other errors involved in the measurement, it is neglected.

In order to cut down the time of exposure, Eastman Superspeed films were used, in spite of the fact that the emulsion is much less uniform than on plates for the optical region. Because of the uneven emulsion and because the lines are not very intense, the errors of photographic intensity measurements with these films may run as high as 30% in extreme cases, although the mean is certainly much less, and is further reduced by taking the average of three or more runs on different parts of the film.

FIG. 1. *Arrangement of tube, scatterers, and spectrometer.*

Another unavoidable source of error is the variation of the scattering angle from its mean value. A number of factors contribute to this variation, two of which are of major importance. In the first place, there is a variation of $\pm\phi_1$ degrees in the scattering angle where ϕ_1 is the angle subtended by the half focal spot at the scatterer. ϕ_1 may be as large as 7° but as the focal spot is limited by a copper diaphragm it can not be larger. The second source of error arises from the penetration of the rays into the scatterer. If we consider only the line on the scatterer from which the modified component originates, the scattering angle varies with the depth below the surface of the scatterer. This variation of scattering angle is represented by ϕ_2 in Fig. 1. ϕ_2 obvoiusly has no definite limits as it is determined by the penetration of the rays into the scatterer. Calculation shows, however, that about 90% of the rays reaching the photographic film are scattered at depths of less than 1 mm for graphite, 2.2 mm for charred sugar, and 3 mm for paraffin.

This results in a maximum variation of about 15° in the worst case

(that of paraffin at 90°), and a variation of about 3-1/2° in the most favorable case (that of graphite at 135°). Attention is called to the fact that this is the total variation, and not the variation about a mean. It is given in this form because it is unsymmetrical.

Two other sources of variable scattering angle which can be largely or totally eliminated are due to the height of the scatterer, and to broadening of the effective focal spot by production of x-rays on the walls of the tube by electrons which have rebounded from the focal spot. The first was largely eliminated by the use of a specially shaped scatterer. For a particular scattering angle, it is possible to generate a surface for which every point in the vertical band on the scatterer from which the scatterered $K\alpha$ radiation originates satisfies the condition that a line through the center of the focus and another horizontally through the slits will meet at a constant angle. This angle is the supplement of the scattering angle. Surfaces of this type were obtained by a convenient graphical method.

Variation of scattering angle caused by production of Cu rays on the walls of the tube was completely eliminated by heavily plating the inside of the tube with nickel and thus eliminating any possibility of copper K rays originating on the walls of the tube. As the walls of the tube are at the potential of the target, no electrons will strike the target itself a second time.

Two small sources of variable scattering angle which may be neglected are the angular width of the slit at the scatterer, and vertical crossfire through the slits.

The total variation of scattering angle will be slightly unsymmetrical, extending farther from the mean in the direction of larger than in that of smaller angles. A rough estimate of the maximum variation from the mean gives $+18°$ and $-11°$ for paraffin at 90°. For graphite at 90° the maximum deviation is probably about $+11°$ and $-8°$. The average deviation from the mean is certainly much smaller, probably not far from $+6°$, $-4°$.

The previously described method of determining the mean scattering angle is subject to an error of about $\pm 5°$.

RESULTS

Because of the variability of scattering angle and the uncertainties of photographic photometry, it is very difficult to draw any conclusions as to the exact shape or width of the modified line. However, as the variation of R as a function of scattering angle is very large compared to the errors involved, results regarding the form of this function may be significant and it is this function which is here determined.

Fig. 2 is one of thirteen spectrograms taken at various scattering angles. Fig. 3 is an energy graph obtained from this spectrogram.

R as determined from these spectrograms is plotted against scattering angle in Fig. 4. The rapid change of R between scattering angles

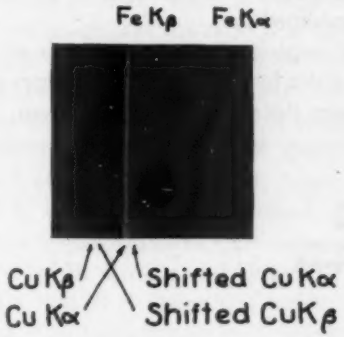


FIG. 2. *Spectrogram of Cu K rays scattered from carbon.*

of 90° and 120° is quite striking. As might be expected, the value of R for paraffin is somewhat greater than that for carbon.

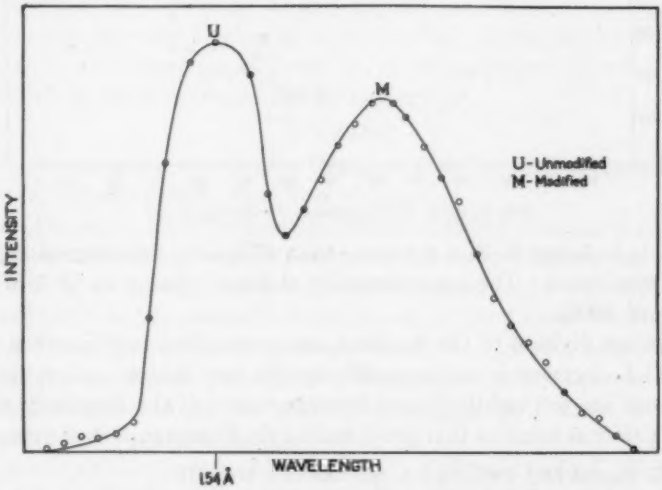


FIG. 3. *Energy graph obtained from spectrogram of Fig. 2.*

No calculation of R has been made for the β lines because of their low intensity, but it is obvious from densitometer tracings that R is much larger for the β lines. This confirms the observations of De Broglie and Dauvillier.[4]

COMPARISON WITH THEORY

Of the theorists who have treated the Compton effect on the basis of wave mechanics, [10, 11, 12, 13, 15] Wentzel is the only one to predict intensity relations. Comparison of these predictions with experiment is very difficult because the wave mechanics predicts very indefinite boundaries for the modified line.

A theory of the Compton effect on the basis of the old quantum mechanics has been given by Jauncey.[14] This theory gives results which can be compared more definitely with experiment. Jauncey's theory

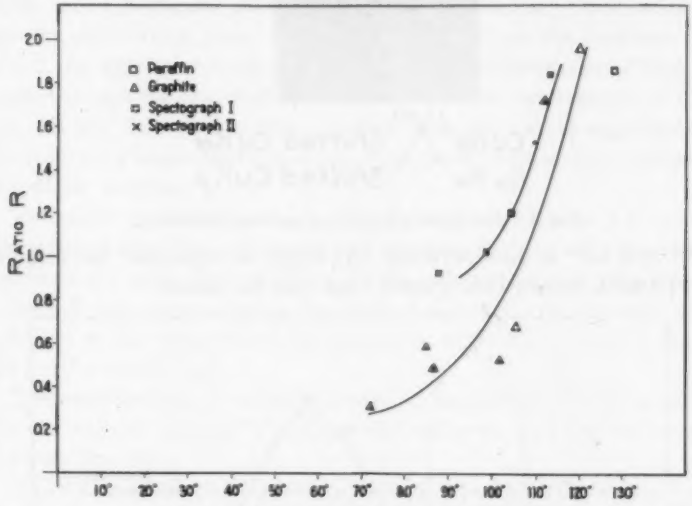


FIG. 4. *Ratio R as a function of scattering angle.*

predicts a change in R of not more than 10% over the range of angles here considered. The experimentally observed change in R is of the order of 400%.

A rough division of the modified and unmodified rays between the K and L electrons is made possible by the fact that in carbon the K electrons are too tightly bound to scatter rays of the frequency used with a shift as small as that predicted by the Compton-Debye formula.

[10] G. Wentzel, ZS. f. Phys., *43*, p. 1, 1927; and *43*, p. 179; 1927.

[11] P. A. M. Dirac, Roy. Soc. Proc., *111*, p. 405; 1926. Proc. Cambr. Phil. Soc., *25*, p. 500; 1923.

[12] W. Gordon, ZS. f. Physik, *40*, p. 117; 1926.

[13] E. Schrödinger, Ann. d. Physik, *82*, p. 257; 1927.

[14] G. E. M. Jauncey, Phys. Rev., *25*, p. 314; 1925. G. E. M. Jauncey, Phys. Rev., *25*, p. 723; 1925. G. E. M. Jauncey, Phil. Mag., *49*, p. 427; 1925.

[15] O. Klein and Y. Nishina, ZS. f. Physik, *52*, p. 853, 1929. Y. Nishina, ZS. f. Physik, *52*, p. 869; 1929.

This means that the modified rays must practically all be ascribed to the L electrons. At first sight one might attempt to go further, since the binding energy of the L electrons is very low, and assume that they scatter modified rays only. This, however, when combined with the law that the total scattering from any electron obeys the classical formula, would lead to the conclusion that the ratio R at any angle here investigated would be nearly equal to the ratio of the number of L electrons in carbon to the number of K, namely 2. Experimentally, R is found to approach 2 at large angles, but to be much smaller at small angles. Hence we must conclude that, while the K electrons scatter only unmodified rays, the L electrons scatter both types, with a preponderance of unmodified at small angles and modified at large angles.

In comparing these spectrograms of CuK rays scattered from carbon with those obtained by De Broglie and Dauvillier,[4] using a beryllium scatterer, it appears that R is higher for carbon than for beryllium. Work done by Ross,[2,16] on primary rays from molybdenum shows that R generally decreases with increasing atomic number, which would lead one to expect a lower value for carbon than for beryllium. The explanation of this anomaly may be that there are 4 L electrons in carbon, whereas beryllium has only two. It also appears reasonable in the light of the considerable contribution to the unmodified component by the carbon L electrons that most, if not all, of the radiation scattered from beryllium K electrons would also be unmodified.

SUMMARY

(1) Spectrograms showing the Compton effect for CuK rays scattered from carbon and paraffin have been obtained.

(2) The ratio, R, of the intensity of the modified component to that of the unmodified has been determined as a function of scattering angle.

(3) It is shown that the L electrons in carbon make a considerable contribution to the unmodified component of the Compton effect.

(4) The only theories of the Compton effect which give formulas for intensities are due to Jauncey and Wentzel. Wentzel's theory is not easily susceptible to experimental check and Jauncey's theory does not agree with the present results.

I take great pleasure in thanking Dr. P. A. Ross, Dr. D. L. Webster, Dr. G. R. Harrison, Dr. K. Lark-Horovitz, and Mr. William W. Hansen for their help and advice, and Mr. B. Stuart for his cooperation in the construction of the apparatus.

PHYSICS DEPARTMENT,
STANFORD UNIVERSITY,
CALIFORNIA.

[16] P. A. Ross, P.N.A.S., *11*, p. 569; 1925.

BANDS OF CONTINUOUS SPECTRUM IN MERCURY

By W. H. Crew and W. N. Thornton

In this paper we present certain experimental observations regarding the production of bands of continuous spectrum in electrically excited mercury vapor; and offer a few speculations as to the origin of these spectra.

Opinion differs as to the origin of the continuous spectrum of mercury; some attribute it to the atom, others to the diatomic molecule. The experimental evidence supporting each of these views is admirably summarized in a recent paper by Robertson, Mackinnon, and Zinn;[1] and they also described experiments of their own which they interpret as being in support of the diatomic origin of the continuous spectrum of mercury. In a paper[2] published at about the same time one of us had also expressed the opinion that the continuous spectrum of mercury was of molecular origin; but that in particular it was to be associated with definite electronic transitions within one of the atoms of a molecular pair.

This opinion has been strengthened by consideration of the results of seven experiments which will be described in a moment. These experiments indicate that certain variations in the electrical circuit of the mercury arc favor the production of continuous spectra and reduce the intensity of the linear spectrum; and at the same time these variations apparently diminish the dissociation of molecules in the arc. For this reason and also because the recombination theory requires such a modifying influence as the atoms of a molecule might exert upon one another, we concur with others in attributing bands of continuous spectra to molecular radiations.

The belief that these bands are truly recombination spectra is substantiated by experiments which show that the two conditions in an arc favorable to the production of bands of continuous spectrum are low current density and low temperature of the vapor. Under the most favorable circumstances we obtained spectra with two strong bands of continuous radiation, having maxima at about λ4500 and λ3300, and only four very weak lines. It will be pointed out later that just these four

[1] Robertson, MacKinnon, and Zinn, J.O.S.A. & R.S.I., *17*, p. 417; 1928.
[2] Crew and Dawson, J. O. S. A. & R. S. I., *17*, p. 261; 1928.

lines and no others are the ones which might be predicted from the recombination theory of continuous spectra.

EXPERIMENTS

The arc used in these experiments was kindly given to us by the Naval Research Laboratory, and was exactly similar to that described in a previous article.[3] In every instance herein described, the arc was excited by a 1 kw, 25 kv, 60-cycle transformer, used in conjunction with a 0.002 microfarad condenser across the secondary and various resistances, capacities, etc., in the remainder of the circuit. Light from the quartz, mercury arc was admitted directly into the slit of a Gaertner, small size, quartz spectrograph.

In the diagrams of circuits given below the position of the arc is denoted by X, and in each case the value of C, was 0.002 microfarads.

Experiment 1. The arc was excited directly from the secondary as

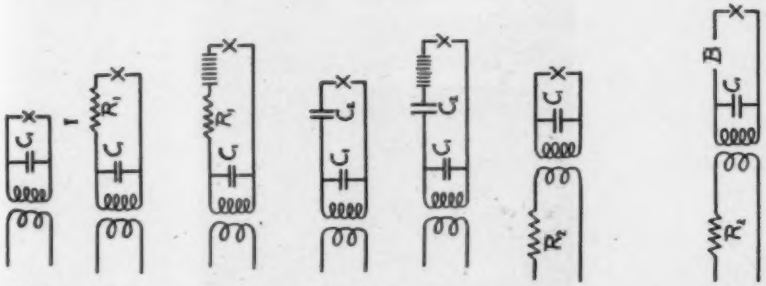


Fig. 1 Fig. 2 Fig. 3 Fig. 4 Fig. 5 Fig. 6 Fig. 7

in Fig. 1. The spectrum is a mixture of lines and continuous bands, as seen in Fig. 8-c. Here the arc was very brilliant and the current density was high. This latter condition we believe to favor the production of lines.

Experiment 2. A high resistance was placed in series with arc as in Fig. 2. In Fig. 8, spectra (a) and (b) were made with R_1 equal to 20,000 ohms and 10,000 ohms, respectively. Here the current density was considerably reduced though the initial potential was high. Probably because of this latter fact the discharge filled the entire cross-section of the arc. It is noticed that the number and relative intensity of the lines is considerably reduced, and that the limits of the continuous spectra are more sharply defined than in the preceeding experiment.

[3] Crew and Dawson, l.c., p. 262.

Experiment 3. In series with the arc and the high resistance of the previous experiment was placed an old type quenched spark gap, Fig. 3. This consisted of about twenty short gaps in series with large copper cooling fins each side of each gap, so that once the gaps break down, the hot ionized gases are quickly dissipated by the fins. Thus only the peak of each voltage alternation caused a discharge through the arc. The current density was correspondingly reduced, and the arc was less intense and distinctly bluer in appearance. In Fig. 8, spectra (d), (e) and (f) correspond to R_1 equal to 20,000 ohms, 10,000 ohms, and zero ohms, respectively. It is noted that the line spectrum is still further suppressed, except in the latter case ($R_1=0$), where the voltage was

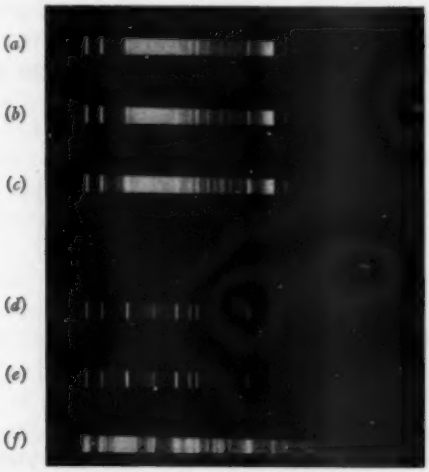


FIG. 8. *Spectra of mercury under various conditions of electrical excitation.*

almost continuously above the break-down potential of the quenched gap.

Experiment 4. A capacity C_2 of 0.004 microfarads was placed in series with the arc, Fig. 4, giving a spectrum identical with Fig. 8-(f). The effect here was to increase the frequency of the oscillations, and at the same time to allow a large current to pass.

Experiment 5. A quenched gap, Fig. 5, was here added to the circuit of Experiment 4. Due to the high frequency of this circuit the gap offered large impedance, resulting in a large decrease of current density. It is seen from Fig. 9-(a) that the line spectrum is almost entirely suppressed, and that the continuous band at λ3300 stands out strongly. It is be-

lieved that had a panchromatic plate been used here, the continuous band at λ4500 would have been equally intense; for the arc, though weak, was a beautiful deep-sea blue color.

Experiment 6. A high resistance, R_2, (Fig. 6) of 1500 ohms was introduced into the primary of the original circuit. This, of course, reduced both current and potential in the secondary. It was observed that in this case there was but a single, thin, thread-like discharge down the center of the tube, so that though the current was small, the current density was probably very high. We attributed this thread-like discharge to the fact that once the arc flashed at one point it continued to follow that path, for the potential would not then be sufficiently high to cause a break down at another point. As might be anticipated from the high current density, we observe in Fig. 9-(b) a spectrum of lines almost devoid of continuous bands, although there is a faint continuous background throughout the entire spectrum. We note with interest what appears to be a reversal of the band at λ2600 against this back-

FIG. 9. *Spectra of mercury: (a) low current density; (b) high current density.*

ground. It is estimated that the light from this discharge passes through about 2 mm of unexcited vapor in emerging from the arc.

Experiment 7. The circuit of the previous experiment was modified as shown in Fig. 7; i.e. the circuit was merely broken at *B*. It seems that the capacity of this gap was sufficient to pass a small current. This gave a very faint blue glow which eminated from the mercury surface of the arc which was the most remote from *B*. This glow looked not unlike auroral streamers, starting from points on the periphery of the mercury surface and spreading out, fan-like, to fill the tube; but not extending to the opposite mercury surface. With the slit of the spectroscope but an inch from the arc and a four hour exposure on a panchromatic plate, the spectrum given in Fig. 10 was obtained. (The comparison spectrum above and below is a mercury line spectrum.) We note on the negative the two continuous bands standing out boldly, and four very faint but sharp lines; namely, λ5461, λ4358, λ4047, λ2536, (and possibly λ3660 very weak). It was observed that if the primary resistance was reduced

but a very little bit, the arc would change from the pure glow condition to a thread-like discharge superposed upon the glow,—a condition which enhanced the lines. On the other hand, if the primary resistance was increased a bit, the discharge would not pass at all; so that in all, the condition which gave the almost pure continuous spectrum was rather critical.

FIG. 10. *Continuous bands from a mercury glow and mercury line comparison spectra.*

Experiment 8. Using the circuit of Experiment 7, Fig. 7, two exposures were made of the arc; one with the external heating coil of the arc just enough to keep the mercury columns apart, the other at a somewhat higher temparature. We observed that the higher temperature reduces the relative intensity of the λ4500 band by about 30 per cent.

DISCUSSION

The bands of continuous spectrum having maxima at λ4500 and at λ3300 have been observed free from line spectrum by other investigators,[4, 5, 6, 7, 8] though never before, it is believed, in a simple electric discharge between mercury electrodes.

In each of these other investigations, which embraced low voltage, hot cathode arcs, electrodeless discharges, fluorescing glows, etc., it is noticed that low current density was the criterion for the successful production of the continuous bands free from line spectra. In keeping with this, we also have observed in the foregoing experiments that every step which acted to decrease the current density tended to enhance the bands.

Do these facts suggest, then, an atomic or molecular origin of these bands? The evidence seems to point toward the latter alternative; for Wood[9] has shown the existence of molecules in vapor freshly dis-

[4] Rayleigh; Proc. Roy. Soc., *119*, p. 349; 1928.
[5] Van der Lingen and Wood; Astrophys. Jl., *54*, p. 149; 1921.
[6] Stark; Ann. d. Phys., *14*, p. 520; 1904.
[7] Child; Astrophys. Jl., *55*, p. 329; 1922.
[8] Deiffieux; Journal de Phys., *9*, p. 61; 1928.
[9] Wood, Journ. Frank. Inst., *205*, p. 481; 1928.

tilled from a mercury surface, and Houtermans[10] has found the dissociation potential of the Hg_2 molecule to be 0.04 volts. Combining these two facts we should expect from the two distilling surfaces in our arc, a plentiful supply of molecules which are readily dissociated by slow moving electrons or ions. Thus one may reasonably associate with the molecules the bands of continuous radiation, which naturally enough grow weaker when the current density is made high enough to break down an appreciable number of these molecules. This view seems further supported by the fact cited in Experiment 7, namely, that the blue glow was close to the liquid mercury surface where, according to Wood's observation, the molecules should be most abundant.

The mechanism by which we suppose the molecule to emit these continuous bands has been described in a previous paper. Here it was shown that on the basis of the recombination theory[11] electrons

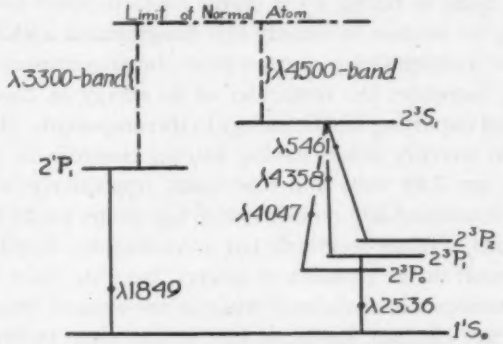


FIG. 11. *Diagram of certain energy levels in mercury.*

with random initial kinetic energies plunge into ionized atoms and cause to be emitted a continuous spectrum which commences at a spectral series limit and extends toward shorter wave lengths; but if the ionized atom is bound in molecular union with another, its orbits may be so modified as to allow the continuous spectrum to extend to each side of a series limit. In the case of mercury, it was pointed out that the bands having maxima at λ4500 and λ3300 seems to correspond with the series limits λ4590 and λ3320. This means that electrons are plunging with various initial kinetic energies into the 2^3S_1 and 2^1P_1 levels, respectively, of ionized atoms of mercury held in molecular bond.

[10] Houtermans; ZS. für Phys., *41*, p. 140; 1927.
[11] Crew and Hulburt; Phys. Rev., *28*, p. 936; 1926.

By reference to the diagram of energy levels, Fig. 11, it seen is that electrons plunging into the 2^3S_1—level may emit four lines, λ5461; λ4358; λ4047; λ2536, in reaching the normal 1^1S_0—level; and it so happens there are no other allowed transitions from 2^3S_1 to lower energy orbits. It was with interest, then, that in Experiment 7 we found the λ4500 band and also just these four lines and no others.

By exactly similar reasoning, the diagram of energy levels suggest that the line λ1849, and no others, should accompany the λ3300 band. We regret that to date we have obtained no plates which extend that far into the ultraviolet.

Robertson, MacKinnon, and Zinn[1] have raised the objection that conditions which render strong bands yield but very weak lines; whereas, by the recombination theory one would expect strong lines, since the multitude of electrons which produced the *multitude* of wave lengths in a band, unite in taking a *few* simple paths to lower levels. On the other hand, we venture to remedy this disagreement with facts by presuming that a recombining electron after plunging into one of the outer orbits may surrender the remainder of its energy in dissociating the molecule and imparting kinetic energy to its components. The available energies[12] in mercury atoms having valence electrons in the 2^3S_1 and 2^1P_1 orbits are 7.69 volts and 6.67 volts, respectively; consequently the energy converted into momentum of the atoms would be 7.65 volts and 6.63 volts,—values seemingly not unreasonable. Possibly the cases which do result in the emission of spectral lines are those few cases in which the molecule is dissociated while in the excited state by collision with a free electron, leaving a free excited atom to emit radiation in the usual manner.

At the same time we are forced to recognize that from knowledge of critical potentials[12] the four lines observed on our plates are the four which require the least energy to excite them in a normal atom.

Temperature Effects; In the experiments of Rayleigh,[13] Wood and Voss[14] and in Experiment 8 of this paper it is observe that increase of temperature tends to quench the λ4500 band. Crew and Dawson (l. c. p. 270) pointed out that the simultaneous quenching of the lines λ5461; λ4358; λ4047 was consistent with the recombination theory. We here venture the speculation that in distillation from liquid mercury two types of molecules are formed, possibly Hg_2 and Hg_3, and that

[12] Mohler; Bul. Nat'l. Res. Council, *9*, Part 1, No. 48; p. 69;1924.
[13] Rayleigh; Proc. Roy. Soc., *A114*, p. 620; 1927.
[14] Wood and Voss; Nature, *121*, p. 418; 1928.

electrons recombining favor the 2^3S_1—level in one type and the 2^1P_1 —level in the other type, and that high temperatures cause thermal dissociation of the type that favors the recombination into the 2^3S_1 —level, thus quenching the λ4500 band.

In a previous paper[2] (p. 268, Fig. 6), one of us has shown a curve giving the wave length distribution of intensity in the two continuous bands of mercury, calculated from an equation which was derived from considerations of the recombination theory. It was necessary to introduce into this equation certain arbitrary assumptions regarding temperature of the free electron gas and deficiency of orbits,—but assumptions which seemed compatible with circumstances.

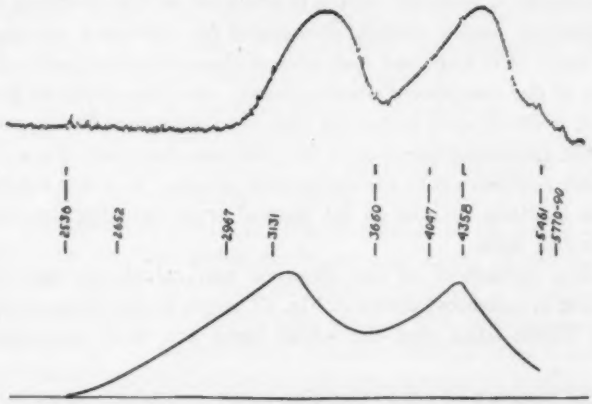


FIG. 12. *Comparison of experimental and theoretical intensity distribution; (above) densitometer curve of Fig. 10; (below) calculated curve.*

Through the courtesy of the Naval Research Laboratory a densitometer curve has been made of the spectrum of Fig. 10, and is shown, Fig. 12, placed in juxtaposition with the theoretical curve copied from the previous paper. The similarity is much more striking than was anticipated when the theoretical curve was derived, although it must still be born in mind that the densitometer curve is by no means a true representation of intensity distribution.

The experimental curve of Fig. 12 has intensity maxima at slightly longer wave lengths than had been calculated; which means that high deficiency of orbits is somewhat more probable than had been assumed.

The four lines λ5461; λ4358; λ4047; λ2536 show clearly on the densitometer curve. There is a suggestion of a line at λ3660, though it was not observed in scanning the plate itself.

CONCLUSIONS

In the seven experiments described, certain changes in the electrical exciting circuit produced considerable changes in character of the resulting spectra. We conclude from these experiments that those changes which reduce the current density in the arc enhance the continuous bands of radiation. It is true that alterations in the circuit will also change the potential and frequency of oscillation in the arc; but experiments at frequencies of 25 to 60 cycles, at 500 cycles, and at 16,000 kilocycles gave no indication of any marked change in character of the spectrum.

We agree with others, that the origin of the continuous bands is in the molecule of mercury, which is produced at the distilling surface of the mercury, and is readily dissociated by even slow moving electrons or ions. It is supposed that some of these molecular pairs of atoms have one of the component atoms ionized, and the electrons plunging into outer orbits of such molecules emit the continuous bands, and that usually the remaining energies of the electrons dissociate the molecules and impart momentum to the component atoms. In a few cases, however, the electron reverts to its normal level emitting the observed weak spectral lines.

The close agreement of the observed and calculated wave length distribution of intensity, shown in Fig. 12, seems to encourage the notion that the $\lambda 4500$ band and the $\lambda 3300$ band are truly recombination spectra.

We take pleasure in acknowledging many courtesies extended us by Professor D. G. Howard of the Department of Electrical Engineering and Physics at the Naval Academy.

POSTGRADUATE SCHOOL,
U. S. NAVAL ACADEMY,
ANNAPOLIS, MD.
21 AUGUST, 1929.

INSTRUMENT SECTION

A NEW VARIABLE STANDARD OF ELECTROMAGNETIC INDUCTION

By Paul E. Klopsteg

The instrument to be described introduces a new element of great simplicity into the electrical arrangements for measuring magnetic flux with a ballistic galvanometer. To review briefly methods of flux measurement requires merely a recitation of the methods that have been described for calibrating the ballistic galvanometer, in circuit with which some form of search coil is connected.[1]

The methods may be classified under four headings. The first comprises those in which the magnetic field used in the calibration is set up by a steady, measureable current; the second employs a standard condenser and known charging voltage; the third utilizes magnetic fields of permanent magnets; the fourth is based on the use of the earth inductor. In the first group there are two kinds of devices which, through the agency of a magnetic field set up by a steady current, produce an inductive impulse corresponding to a known value of line-turns. These are (1) some form of standard mutual inductometer; and (2) the Duddell inductor, a specialized form of variable mutual inductometer. The first of these groups comprises the standard solenoid with fixed search coil, or secondary, which may be tapped at several points; the fixed standard of mutual inductance; and the variable standard of mutual inductance, such as the Brooks and the Ayrton-Perry forms. The Duddell inductor consists of two fixed and two movable coils, astatically arranged, with provision for sudden rotation of the movable coils through 180° in the magnetic fields of the fixed coils. Any such calibrating device requires a storage battery, a rheostat, a simple or reversing switch or key, and means for measuring the current accurately. If an ammeter is used for this measurement, the attainable accuracy is no greater than that of the meter and that with which the constant or the calibration of the mutual inductometer is known. If a potentiometer is used with a standard resistance, the circuits become too complicated for ordinary laboratory use.

[1] See, for example, *Dictionary of Applied Physics*, 2, "Magnetic Measurement", p. 457.

The second method is that of discharging a standard condenser, at known initial voltage, through the galvanometer, and immediately closing the galvanometer circuit through the circuit with which the flux measurements are to be made. This may be accomplished with the device known as the Zeleny key.[2] The fact that the galvanometer coil swings on open circuit for a very short but necessarily variable time interval renders difficult the estimation of the probable error of the measurement. This uncertainty, together with the probable error in condenser capacity, affects the results to the extent of perhaps $\pm 0.5\%$.

The simplest arrangement hitherto described is the Hibbert magnetic inductor.[3] A search coil is made to fall through the annular air gap of a special permanent magnet, and the line-turns value for any particular coil is given. A tapped coil,[4] giving three values of line-turns, is available, but, in general, individual, narrow coils give results which leave less doubt as to accuracy than does the tapped coil.

A fourth method, little used but, for completeness of account requiring mention, is the earth inductor. Its use is limited to locations in which H or V is accurately known. The relatively slow rotation of the inductor coil causes the discharge to be prolonged, which results in deviation from proportionality of discharge and throw, a relation which holds strictly for instantaneous discharge only. Hence the accuracy is somewhat uncertain and the probable error difficult to estimate.

The Hibbert inductor, because of its simplicity and convenience, since it requires none of the accessories mentioned in connection with the current inductors, recommends itself as the calibrating means to be selected from the group enumerated. There is one criticism to be made of it, namely, its lack of flexibility. In a calibrating device of the kind under discussion, it is important that numerous values of line-turns be available, in order that the ballistic galvanometer scale may be checked over its entire useful range.[5] By the current inductor methods this can be done readily, but their complexity is a deterrent to their use.

The new calibrating instrument was designed to combine the simplicity of the Hibbert inductor with the range of the current inductors. The writer has had the plan of the instrument in mind for many years,

[2] Zeleny, A., Phys. Rev., O. S., *23*, p. 399; 1906. There are other, more important applications of this ingenious key.

[3] Phil. Mag., *33*, p. 307; 1909.

[4] It should be remembered that a tapped coil, whether on a mutual inductor or a Hibbert inductor, introduces the difficulty of a change in the circuit resistance, and hence in the discharge as well as in damping, with each change of connection.

[5] Klopsteg, Phys. Rev., N.S., *5*, p. 266, 1915; *7*, p. 636, 1926

but has found it possible only within the past year to work out the details. The objective was to develop an inductor which would provide values of line-turns to cover a range suitable for complete calibration of a galvanometer scale—if possible without the need of auxiliary apparatus—and which would not introduce resistance variations of the galvanometer circuit. The result of the work is a calibrating device that has proved itself satisfactory beyond expectations and that far surpasses in convenience of use, and equals in accuracy, the other devices mentioned above.

As developed, the instrument has the external appearance of an electric meter (See Fig. 1) and it embodies some of the parts of the latter. It has the magnet, pole-pieces and core of the meter, and it has a

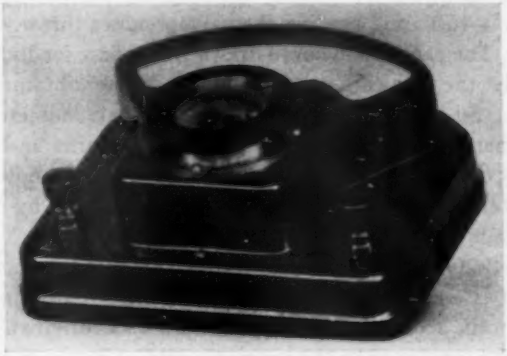


FIG. 1. *Variable magnetic inductor.*

movable coil; but the latter is used as a generator, not as a motor, as in the Weston type of direct current meter. The coil is wound on a sturdy frame, and its mountings are in keeping with the frame. Springs of much greater torque are used than in the meter. To the coil is attached an indicator consisting of a hair line carried by a stiff arm. The hair line moves over the mirror scale, and with its aid the angular position of the coil, or line-turns equivalent of such position, is precisely readable. Coaxial with the coil, and mounted on the case of the instrument so that it may be rotated, is a ring of Bakelite, to which is attached a simple mechanism for turning the coil to a selected position in the magnetic field. A small spring catch grasps the arm attached to the coil when the ring is turned counterclockwise to a stop. The ring is then turned in the opposite direction until the hair line indicates

the desired value of line-turns on the scale. Pushing a small button in the ring releases the catch; the springs snap the coil back to the zero stop, where another catch seizes the arm and prevents rebound. The coil has thus been suddenly turned in the field through a predetermined angle, corresponding to the indicated value of line-turns. The scale has ten calibration points; the experimentally determined values of line-turns are marked at the corresponding points.

The use of the variable magnetic inductor in a measuring circuit is so simple that a very brief description suffices to explain it. The inductor is connected in series with the ballistic galvanometer and search coil. Assuming that throws from the latter will be of different magnitudes, in a given experiment, the best procedure is to calibrate the ballistic galvanometer by setting the inductor on each of its calibration points in turn, and reading the galvanometer throw when the coil is released. The calibration curve drawn from these readings then gives immediately the line-turns value of any throw obtained with the search coil. So long as the resistance in the galvanometer circuit remains unchanged, the galvanometer is a line-turns meter or, with the number of turns and mean area of the search coil known, a field intensity meter which can easily be checked at any time by means of the magnetic inductor.

The question of accuracy of the variable magnetic inductor has been studied. It is a secondary standard instrument, depending for its accuracy upon the accuracy with which the scale was originally calibrated, and upon the constancy of the magnetic field. Change in the magnetic field with normal use is negligible, since the magnet receives the same treatment as do meter magnets. The accuracy therefore closely approaches the accuracy of the original calibration. This, with proper precautions, may be brought within $\pm .2\%$. The fact that settings of the indicator are made only on the original calibration points eliminates questions of scale accuracy between such points. The hairline indicator, with mirror scale for avoiding parallax, insures accuracy of setting quite within 0.2% except at the two lowest points on the scale. Here the accuracy is somewhat less, but still within 0.5%. However, such accuracy is not attainable in the current inductor methods ordinarily used. To attain or exceed it would require the use of a standardized ammeter or of a potentiometer in the measurement of the primary current.

CENTRAL SCIENTIFIC COMPANY,
CHICAGO, ILLINOIS.

A METHOD OF INCREASING THE SENSIBILITY OF THE DOLEZALEK TYPE ELECTROMETER; AND A DIRECT READING "NULL" CIRCUIT

By John M. Pearson

In connection with some studies being made on the scattering of electrons by gases, we have found ourselves in need of a means of measuring currents over a range of several orders of magnitudes. The method developed below has been found so satisfactory and convenient, that it is thought, perhaps, to be of general interest.

The scheme makes use of a Dolezalek electrometer, of comparatively rugged construction, which has been slightly modified to increase its sensibility. This instrument is used as an element in a null circuit that is direct reading, and that can be adjusted electrically to cover a wide range of orders of magnitude of current.

I. SYNOPSIS OF THE THEORY

Let $C_1(\theta)$ = Capacity of needle and quadrants "1."

Let $C_2(\theta)$ = Capacity of needle and quadrants "2."

(See Fig. 1.)

Let V_1 = Potential of quadrant "1" above the instrument case.

Let V_2 = Potential of quadrant "2" above the instrument case.

Let V_3 = Potential of needle above the instrument case.

Let T_0 = Moment of torsion of fiber.

Let θ = Angular displacement of needle.

Then we can write the total potential energy of the suspended system as

$$E=(V_3-V_1)^2\frac{C_1}{2}+(V_3-V_2)^2\frac{C_2}{2}+\frac{1}{2}T_0\theta^2.$$

In equilibrium, $-dE/d\theta=0$. So if V_3 = constant.

$$-\frac{dE}{d\theta}=(V_3-V_1)C_1\frac{dV_1}{d\theta}+(V_3-V_2)C_2\frac{dV_2}{d\theta}$$

$$-\frac{(V_3-V_1)^2}{2}\frac{dC_1}{d\theta}-\frac{(V_3-V_2)^2}{2}\frac{dC_2}{d\theta}-T_0\theta=0.$$

Then we have:

(1) The mechanical zero is at $\theta=0$.

(2) At the electrical zero,

$$V_1=V_2=\frac{dV_1}{d\theta}=\frac{dV_2}{d\theta}\equiv 0. \quad V_3\neq 0$$

so

$$\frac{V_3^2}{2}\left\{\frac{dC_1}{d\theta}+\frac{dC_2}{d\theta}\right\}+T_0\theta=0$$

Now, $dC_1/d\theta>0$ and $dC_2/d\theta<0$ by the convention of the direction of increase of θ. Hence if the electrical and mechanical zeros coincide, $|(dC_1/d\theta)_{\theta=0}|=|(dC_2/d\theta)_{\theta=0}|$ since $\theta=0$.

(3) Voltage sensitivity can be defined by

$$S_v=\left(\frac{\partial\theta}{\partial V_1}\right)_{v_2,v_3\ \text{constant}}$$

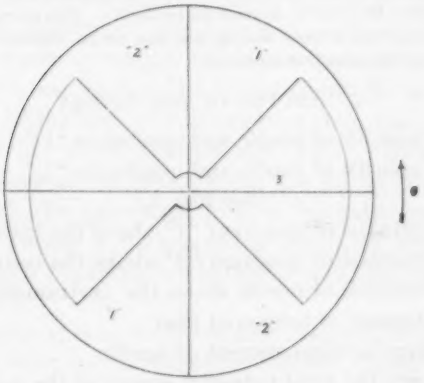


FIG. 1.

Where in equilibrium,

$$\left.\begin{array}{ll} V_1\neq 0 & \dfrac{dV_1}{d\theta}\equiv 0 \\ V_2\neq 0 & \\ V_3\neq 0 & \dfrac{dV_2}{d\theta}\equiv 0 \end{array}\right\} \therefore -\frac{(V_3-V_1)^2}{2}\frac{dC_1}{d\theta}-\frac{(V_3-V_2)^2}{2}\frac{dC_2}{d\theta}-T_0\theta=F=0.$$

So

$$S_v=\left(\frac{\partial\theta}{\partial V_1}\right)_{\text{equilibrium}}=-\frac{\dfrac{\partial F}{\partial V_1}}{\dfrac{\partial F}{\partial\theta}}=+\frac{(V_3-V_1)\dfrac{dC_1}{d\theta}}{\dfrac{(V_3-V_1)^2}{2}\dfrac{d^2C_1}{d\theta^2}+\dfrac{(V_3-V_2)^2}{2}\dfrac{d^2C_2}{d\theta^2}+T_0}.$$

The denominator can be made as small as desirable, since $T_0>0$, $(V_3-V_1)^2>0$ and $(V_3-V_2)^2>0$, if the second derivatives are negative.

When these derivatives are negative we have what Compton[1] calls "negative electrostatic control"; and when they are positive, "positive electrostatic control." The first case amounts to a reduction, the second to an increase in the effective moment of torsion.

(4) A null method is suggested by the following inspection: Consider the needle always in equilibrium at an angle θ, kept there by properly adjusting V_2 as V_1 changes. As before,

$$-\frac{(V_3-V_1)^2}{2}\frac{dC_1}{d\theta}-\frac{(V_3-V_2)^2}{2}\frac{dC_2}{d\theta}-T_\theta\theta=0.$$

$$\therefore V_3-V_2=+\sqrt{-\frac{(V_3-V_1)^2\frac{dC_1}{d\theta}+2T_\theta\theta}{\frac{dC_2}{d\theta}}}\quad(0<V_3>V_2).$$

Then

$$\frac{\partial V_2}{\partial V_1}=\left\{\frac{\partial(V_3-V_2)}{\partial(V_3-V_1)}\right\}_{\substack{V_3=\text{const.}\\ \theta=\text{const.}}}=\sqrt{-\frac{1}{\frac{dC_2}{d\theta}}}\,\frac{(V_3-V_1)\frac{dC_1}{d\theta}}{\sqrt{(V_3-V_1)^2\frac{dC_1}{d\theta}+2T_\theta\theta}}.$$

$$=\sqrt{-\frac{1}{\frac{dC_2}{d\theta}}}\,\frac{\frac{dC_1}{d\theta}}{\sqrt{\frac{dC_1}{d\theta}+\frac{2T_\theta\theta}{(V_3-V_1)^2}}}.$$

Thus if we take the mechanical zero, $\theta=0$, as a null point we have:

$$\frac{\partial V_2}{\partial V_1}=\sqrt{-\frac{\left(\frac{dC_1}{d\theta}\right)_{\theta=0}}{\left(\frac{dC_2}{d\theta}\right)_{\theta=0}}},$$

which is a constant independent of needle or quadrant voltages. Experimentally, of course, how small a "dV_1" can be detected at $\theta=0$ depends upon S_v which in turn depends on V_3, etc. If the electrical and mechanical zeros coincide, by (2)

[1] A. H. Compton and K. T. Compton, Physical Review, *14*, p. 90; 1919.

$$\left(\frac{dC_1}{d\theta}\right)_{\theta=0} = -\left(\frac{dC_2}{d\theta}\right)_{\theta=0} \therefore \frac{\partial V_2}{\partial V_1} = 1 \quad \text{and} \quad V_2 = V_1 + V_0$$

but since the electrical zero is $\theta = 0$, $V_0 = 0$.

II. EXPERIMENTAL ARRANGEMENT

(5) The arrangement to make $d^2C_1/d\theta^2 < 0$ and $d^2C_2/d\theta^2 < 0$ is as follows: The needle is first bent on its axis as in Fig. 2, so that when the quadrants are level the right hand end "A" is about one fifth the way from the bottom to the top, and the left hand end "B" the same distance down from the top to the bottom of the quadrants. Next the instrument is tilted about the axis MN, down in back as seen in Fig. 2.

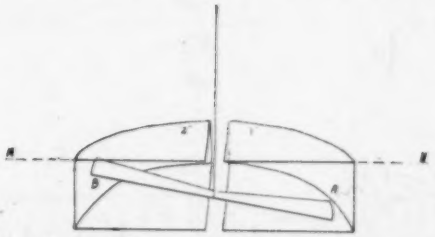


FIG. 2. *Front halves of quadrants and needle removed.*

This brings about the desired condition, as can be seen from Fig. 3. The arrows indicate the positive direction of θ. It is seen that for the "A" end of the needle, positive rotation not only moves the needle out of quadrant "2" and into quadrant "1," but also increases the spacing of the needle from the bottom of quadrant "2." Therefore, since the capacity contributed by the top side of the needle is much smaller than that contributed by the bottom side, $d^2C_2/d\theta^2 < 0$. And in moving into quadrant "1" the advancing edge of the "A" end of the needle gets farther from the bottom so $d^2C_1/d\theta^2 < 0$. Exactly the same kind of argument holds for the "B" end of the needle and the tops of the quadrants.

The instrument used had two levelling screws in a line parallel to MN, and one centrally in back as seen in Fig. 2. By adjustment of the first two screws, and the height of the needle, the electrical and mechanical zeros could be brought approximately together. Further adjustments, as for zero drift, are made with the third screw. A very convenient means of doing this would be that described by Watson[1] in his recent paper on "Current Measurement with the Compton Electrometer."

[1] E. E. Watson, Proceedings of The Cambridge Philosophical Society, *25*, Part I, p 74; 1929.

By raising the needle voltage V_3, the instrument can easily be made to approach instability. We used a Dolezalek instrument with the suspension which gives normally 800 mm/volt. By making the above changes we could operate regularly at 8000 mm/volt. We could attain double this, but only temporarily since the instrument was on a stand that would not remain accurately enough level with slight temperature changes.

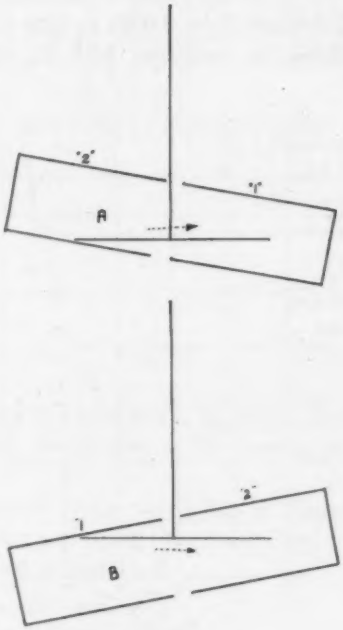


Fig. 3.

A curve of sensibility with needle voltage, obtained by letting $V_2=0$ and $V_1=0.001$ volt, is given in Fig. 4. With this adjustment the point of instability was 97 volts. It was found possible to adjust so that there was a range of several centimeters about the null point in which S_v was sensibly constant.

(6) The null method: Fig. 5 shows the diagram of the circuit used. By filtering the V_2 and V_3 leads with condensers and resistances as shown, it was found unnecessary to shield them. The condensers "C" are 2μf; and the resistances "r" are 1/2 megohm leaks. These

resistances, besides taking part in the filter, make it possible to ground any part of the instrument without measureably disturbing the external circuits.

The potentiometer P_1 is used to control the needle voltage.

The potentiometer P_2 supplies a known voltage to an Ayrton shunt "S," from which V_2 is derived. The voltmeter can conveniently have a range of 10 volts.

The result that $V_2 = V_1$ of (4), above, has been checked as closely as the meters could be read from 0.0001 to 10.0 volts. When V_1 and V_2 become appreciable as compared with V_3, S_v is automatically

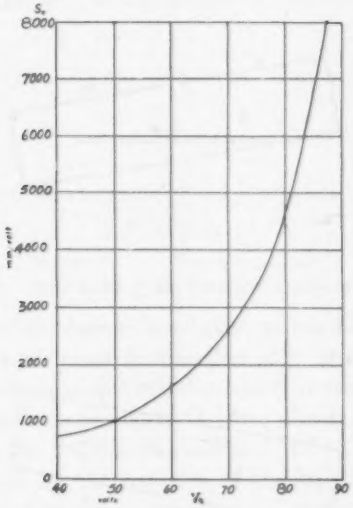


FIG. 4.

reduced provided the polarity of V_3 is chosen correctly. Otherwise V_3 can be reduced for high voltages to make the needle less agile.

The resistance R is a line of india ink on soft drawing paper, thoroughly boiled out and sealed in paraffin. After many trials we succeeded in making one that is constant at $2 \cdot 10^{11}$ ohms. Using this R the instrument and circuit can measure currents over a range from 10^{-15} to $0.5 \cdot 10^{-10}$ Ampères directly.

In manipulating the operator can use P_2 and the reversing switch to set the spot of light on the null point. With a little practice this can be done in a few seconds and a reading made. When measuring very

small currents, because of the inertia of such a large needle, it is necessary to wait a few seconds to be sure the needle is balanced.

With so high a value of R, and if the circuit connected to quadrants "1" has a low enough capacity, the condition that $dV_1/d\theta = 0$ is not satisfied for rapid changes in θ. This operates to make the instrument

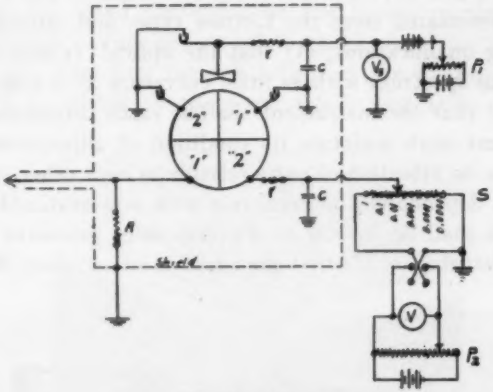


FIG. 5.

more stable to sudden changes in V_2, by virtue of the charge induced on quadrants "1" by the motion of the needle, without introducing an appreciable "lag."

In conclusion I should like to thank Mr. W. Arnquist for his patient assistance in adjusting and using this circuit, and Dr. L. A. DuBridge for the technique used in making R.

NORMAN BRIDGE LABORATORY OF PHYSICS,
CALIFORNIA INSTITUTE OF TECHNOLOGY,
PASADENA, CAL., AUGUST 1, 1929.

A NEW QUARTZ SPECTROGRAPH

By Henry F. Kurtz

This description covers a quartz spectrograph of the conventional type as differentiated from the Littrow type, and intended to meet the following qualifications; (1) that the optical system shall define a sharp, clean spectrum with as little curvature as is consistent with economy, (2) that the instrument shall be easily adjustable, (3) that the instrument shall maintain its condition of adjustment, (4) that there shall be no vibration of parts relative to each other, (5) that the the slit be a dependable, bilateral one with non-oxidizable jaws, (6) that all parts shall be, insofar as is practicable, protected from dust, fumes and disturbance, (7) that the addition of accessory illuminating

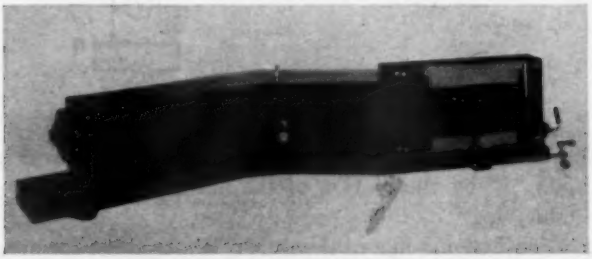


Fig. 1. *General view of the quartz spectrograph from the front. Note the single cast iron base extending the full length of the instrument and projecting beyond the slit. At the center of the top of the case is a removable cover giving access to the prism and lenses. At the center is a knob operating a removable elliptical diaphragm. Directly below this knob at the side of the case is seen the camera lens focusing button and drum. At the right end is the plate holder.*

or photometric apparatus shall be made conveniently and that the combination shall comprise substantially a single apparatus after the addition is made, (8) that the finish shall be servicable and durable.

The first condition, viz. that concerning the optical system has been met by reducing the aberrations to the lowest minimum consistent with economy in the number of elements required and by using crystal quartz of the finest quality of which to make them. The collimator lens is a single piece of quartz, while the camera lens consists of two meniscus lenses separated by an air space. Spherical aberration and

coma are reduced to a minimum. The residual curvature of field is very small, well within the bending limits of the plates used. Plate breakage is therefore rare. This bending might have been further reduced or practically eliminated by means of a more complicated lens construction, but the extra complication, cost, light loss and danger of reflected images and flare make such a construction inexpedient.

The remaining seven conditions are met by the mechanical design. The spectrograph is made of metal throughout. A substantial machined cast iron base extending the full length of the instrument forms a "back-bone" to which all parts are rigidly fastened. Those parts

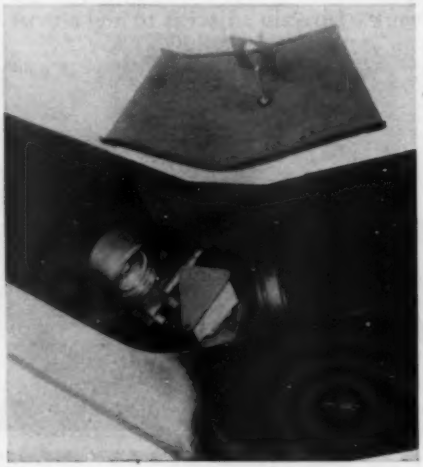


FIG. 2. *View from the top rear with cover removed showing prism and lenses mounted.*

requiring adjustment are provided with facilities for it, and are further fitted with clamping means, so that parts may be locked in position after adjustment. All parts, including the plate holder, are made of metal. This construction assures rigidity and permanence of adjustment as well as freedom from vibration. The instrument is enclosed by a formed sheet metal housing, provided with septa dividing it into three compartments, one serving as collimator, the central one as the prism housing and the other as the camera chamber. These septa serve to suppress stray radiation. The central prism compartment is provided with a cover that may be removed if it is found necessary to adjust the prism.

The outer end of the collimator compartment is closed by the slit supporting bracket. The slit is bilateral with jaws of non-oxidizing material. The micrometer screw operating the slit is provided with a drum reading to 0.01 mm. The mechanism is such that lubrication is unnecessary, and the slit will not "stick." All moving parts are enclosed in a dust-proof case. The entrance aperture is closed by a thin quartz plate, completing the protection of the mechanism. The mechanism is such that the jaws cannot be injured by jamming. A removable photographic shutter is provided making it possible to control exposure accurately. This shutter is held by a removable adapter, so that biprisms or other parts may be attached in its place for spectrophotometric or other work. Directly adjacent to and almost in contact with

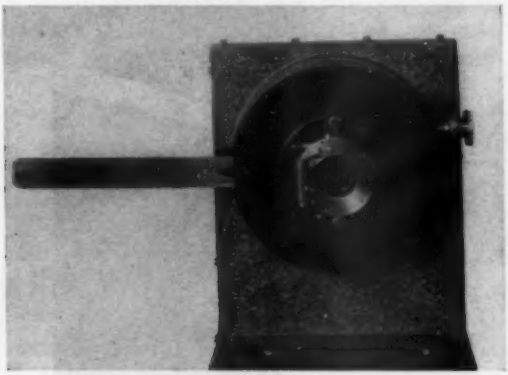


FIG. 3. *View of the slit end of the instrument showing micrometer drum, photographic shutter, and slit for varying slit length.*

the slit is a slide provided with a long, horizontal V and a series of apertures. The length of the slit may be adjusted by means of the V and the apertures permit the exposure of a single or three or four spectra in juxtaposition. Snap stops are proved to facilitate location of these apertures.

The collimator lens is supported by a metal bracket fixed in place at the factory and is non-adjustable. This is done to insure the location of the lens in the position for which the optical system is corrected.

The prism is held on a metal support providing means, with clamps, for rotational and leveling adjustments. The prism is held on its seat by a bridge strap and cleat arrangement in thin cork buffers, assuring good support without strain.

The camera lens is supported on a metal bracket provided with means for adjusting the lens about a vertical axis and clamping it. This adjustable lens assembly is carried on a slide extending along the axis of the instrument in such a manner that the lens can be focused from without the case by rotating a knurled button. The drive is rack and pinion, and the button is provided with a drum divided arbitrarily, so that settings may be recorded for future reproduction.

The plate holder support is a heavy machined iron casting permanently bolted to the base. An additional plate provided with push-pull adjusting screws carries a vertical slide, into which in turn, the plate holder may be inserted. These screws permit adjustment of

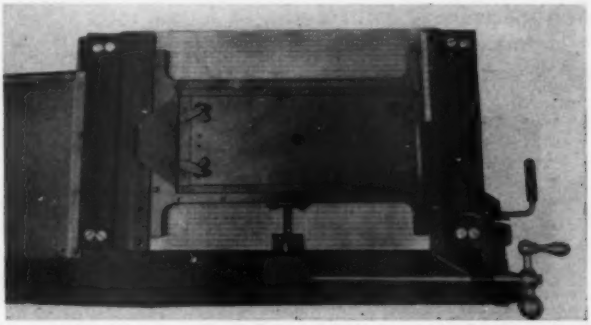


FIG. 4. *The plate holder end of the instrument with plate in position but without the dark slide drawn. The crank operates the plate holder mechanism. The lever above it is for bringing the wave length scale into contact with the plate. The push-pull screws at the four corners of the plate holder support are for adjustment of plate position.*

the photographic plate to the focal plane with a high degree of precision both vertically and horizontally. The type of adjustment provided tends to discourage tampering and will premanently retain its position. The plate holder may be moved vertically in the focal plane by means of a screw and conveniently located hand wheel. A scale, divided in millimeters, is provided so that multiple exposures may be made on the same plate.

The plate holder frame is made of aluminum casting, fitted with a metal slide and a metal back cover to permit loading. This cover is fitted with springs to force the plate to the correct curvature without straining it. The plate is held against two metal seats extending over its entire length.

The base, at the slit end of the instrument projects beyond the slit supporting bracket and is fitted with four holes tapped to receive standard machine screws. These holes are accurately located with respect to the slit, so that any accessory apparatus may be bolted to the base. This arrangement prevents any motion of accessory apparatus with respect to the slit, after adjustment.

A removable wave-length scale is provided. A handle permits it to be brought into contact with the unexposed plate in such a manner that all other parts of the plate are covered. A small electric lamp may be energized with a switch, so impressing the scale directly on the plate. The scale is easily introduced and removed and it is provided with lateral adjustment permitting checking and adjustment to the lines of any known spectrum.

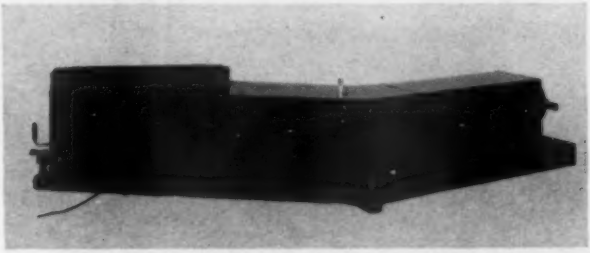


FIG. 5. *View from the rear showing two of the leveling screws and the wave-length illuminator with its tumbler switch.*

Cast parts of the instrument are finished with black crystal lacquer. The machined and smooth parts are finished with a smooth black lacquer not so lustrous as to permit annoying reflections, but of sufficient smoothness to permit easy cleaning.

The collimator lens is of a single piece of quartz, of 610 mm focal length for sodium light, and a diameter of 50 mm. The camera lens is composed of two different meniscus elements separated by an air space. The curved sides are directed away from the plate, thereby eliminating parasitic images of the slit. The focal length and aperture values are the same as for the collimator lens. The prism is of the Cornu type, made of two $30° \times 60°$ prisms, one of right quartz and one of left held together by optical contact. Right and left quartz are balanced against each other throughout the optical system and the crystal axes are so located in the elements that double refraction is neutralized. The image formed on the plate is therefore completely freed from doubling.

The slit is a separate assembly, completely enclosed in itself against dust, fumes etc. This assembly is held to the prism bracket by screws not easily available to mischievous fingers, yet sufficiently easily removable to permit any necessary repair. It is bilateral and the least reading is 0.01 mm. The entrance aperture is protected by a removable plane quartz plate close to the slit jaws, and between them and the photographic shutter.

The plates used are standard 4″×10″ size and are required to bend only through a saggital height of 1/8 inch in the ten inch length. Metal cleats of the correct curvature form a seat for the plates. The wave-length scale is calibrated from 2100 to 7000 angstrom units.

It has been found that an instrument built in the manner described does not suffer from loss of adjustment due to vibration and usage. In fact, the instrument has been demonstrated to maintain working adjustment over a long period of time during which it had ordinary laboratory usage, and even suffered unwarranted abuse in the way of transportation within the laboratory buildings.

SCIENTIFIC BUREAU,
BAUSCH AND LOMB OPTICAL COMPANY,
ROCHESTER, N. Y.

TIME MEASURING BY COMMERCIAL ALTERNATING CURRENT WITH CONTROLLED FREQUENCY

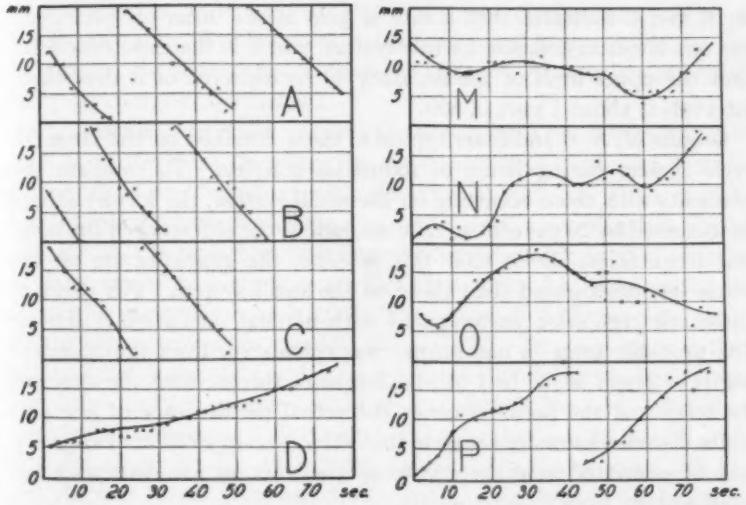
By John Mead Adams

The introduction of controlled frequency on commercial alternating current lines suggests the use of synchronous motors for time measuring and time signalling in the laboratory, and makes it desirable to investigate the degree of accuracy attained in the control of frequency over intervals of the order of 1 sec. The accuracy over long intervals is known to be sufficient for all but the most exacting requirements, and is not under consideration here. This paper deals with the frequency maintained from second to second by two utility companies, one a comparatively small concern serving a part of the city of Los Angeles, the other a system about five times as large, with its lines extended over ten counties of southern California.

The first company operates two steam plants, with a total installed generating capacity of about 199,000 hp. The total connected load is 425,000 hp, of which more than two-thirds is classified as lighting, the remainder being used industrially as power. The nominal frequency is 60 cycles per sec., and regulation is accomplished by periodical inspection and manual adjustment. The second company has hydro-electric plants generating a maximum of 588,000 hp, and steam plants capable of supplying 484,000 hp, all interconnected, giving a total installed generating capacity of 1,072,000 hp. Their total connected load is 1,940,000 hp, widely diversified in character. The nominal frequency of 50 cycles per sec. is controlled by automatic regulators, applied during the day at a steam plant, during the night at a hydro-electric plant. The daytime regulation is the closer.

The variations of the actual cycles per sec. from the nominal value were measured by reference to a standard pendulum with a half-period adjusted to 1.0000 ± 0.0002 sec. In each half-period this pendulum operated a relay which momentarily interrupted the primary current in an induction-coil. The secondary of the coil was connected to a spark gap with a condenser across it. An abrupt bright spark was thus obtained at intervals of almost exactly one second. From this spark the light, rendered parallel by a lens, was directed normally upon a brass disk, about 10 cm in diameter, which was mounted on the shaft

of a small four-pole single phase synchronous motor driven from the line under investigation. On the face of the disk a single turn of a spiral with a pitch of 2.2 cm had been scribed, and along this curve small holes, evenly and closely spaced, had been drilled through the disk. On looking through these holes toward the light, a portion of the spiral appeared illuminated at every spark; and when the field of view was limited by a screen with a radial slot 0.3 cm wide, fixed in front of the disk, the position of the short arc of spiral seen through the slot could be read against a millimeter scale ruled along one edge of the slot. It is plain that with these arrangements an excess or a deficiency of



Accumulated error in total number of cycles, as a function of the time. 1 mm=0.09 cycle.

0.09 cycle in the nominal 50 or 60 cycles would result in shifting the illuminated line one scale division between successive appearances. Practically the range of the instrument is ample, since the frequency almost never varies, in one second, more than a small fraction of a cycle per sec.

Specimen data obtained on the small 60-cycle system are plotted in graphs *A*, *B*, *C*, *D*. Seconds are plotted horizontally, scale readings vertically. Graphs *A*, *B*, *C* show the system losing at rates from 0.06 to 0.09 cycle per sec., and therefore running between 59.94 and 59.91 cycles per sec. Graph *D* shows the system gaining at an increasing

rate, 0.013 at first, 0.033 a minute later. Data for the first three graphs were taken within an hour preceding noon on a Saturday, and they are representative of many others obtained during that hour. Graph *D* was obtained between 12:30 and 1 P.M. of the same day. Shortly afterward, the rate of gain became practically zero for a period of several minutes, indicating an output of 60.00 cycles per sec. during that time. The graphs give no evidence of periodic fluctuations attributable to "hunting" of the motor. The irregularities in the individual observations are believed to be due in large measure to slightly erratic behavior of the relay and to personal errors of the observer. Aside from these fluctuations, however, the general gradient of such graphs as *A*, *B* and *C* indicates that a rate of gain of the order of ± 0.1 cycle per sec. is not uncommon on this system, and it is therefore concluded that the upper limit of the accuracy to be expected of it over short intervals is about 1 part in 600.

Graphs *M*, *N*, *O* and *P* are typical of those obtained on the large 50-cycle system during hours of industrial activity. To compare the gradients with those occurring on the small system, the former should be increased by 20 per cent to take account of the difference in the nominal frequencies. Even after this is done, the gradients are on the whole less pronounced than those on the small system. The effect of automatic regulation as compared with manual regulation is shown. The probable error in one second was calculated, from the observed points of graph *M*, to be 1 in 514; but since this includes the errors of the relay and the personal error, the actual performance of line and motor is somewhat more accurate than this. The upper limit of accuracy may be estimated from the maximum gradients, as was done with the small system, to be about 1 in 800.

To sum up: a synchronous motor, driven from a commercial supply with controlled frequency, may be depended on for a single measurement of a time interval of the order of 1 sec. with a probable error of ± 0.0017 sec. When the intervals to be measured are longer, or when the experiment admits of making repeated measurements of identical intervals, a system with automatic control of frequency may be expected to give results of which the probable error is considerably less than this value.

DEPARTMENT OF PHYSICS,
UNIVERSITY OF CALIFORNIA,
LOS ANGELES, CALIFORNIA.

A NEW PHOTOMETER HEAD

By A. H. Pfund

In a previous article[1] the writer described a photometer which involved the use of a silvered or platinized glass plate which was broken in such a manner as to yield a perfect photometric edge. Recently it was found possible to modify the procedure in such a manner as to eliminate the metallic coating entirely. As a result it is now possible to make out of plate glass an essentially perfect photometer-head of almost any size. Furthermore, it becomes possible to combine in one instrument the three types of photometer-head: (1) equality of brightness; (2) contrast; (3) flicker.

The essential operation consists in cracking a piece of plate glass in such a manner that the plane fractured surfaces reveal no detectable curvature at the boundary with the original surfaces. This may be accomplished as follows: a piece of plate glass, approximately $5 \times 2.5 \times 1/4$ inches is scratched with a steel-wheel glass cutter at A (Fig. 1). A short crack running through the glass plate (i.e. only under the scratch) is started by tapping the plate vigorously with the glass cutter on the side of the plate opposite the scratch. The glass plate is then laid on a flat metal plate and is heated slowly and uniformly from above and below until a temperature of about 150°C is reached. Finally a very hot bunsen flame is directed on the upper surface at B and, occasionally, along the line AB. Suddenly the plate cracks along this line and the two halves jump apart. Inspection reveals that the fractured surfaces are perpendicular to the original ones and that, in certain regions, both edges are essentially perfect. These regions are marked off and trimmed for insertion into the photometer-head. The device is to be termed "photometer-plate."

As shown in Fig. 2A it is possible to unite the beams I, II and III in the photometer plate. Since the length of the light-path in glass and the reflection losses are identical for beams II and III, the perfect symmetry essential to an equality of brightness photometer is

[1] A. H. Pfund, Phys. Rev., *4*, p. 477; 1914.

Footnote: Since an equality of brightness photometer requires but a single edge, the latter may be simply produced by starting a crack, as described, and then breaking the glass by applying force.

realized. In other words, when the edge *E* has been caused to disappear, an "equality of brightness" match has been established (Fig. 2B).

Because of the fact that beam I has suffered no losses, it will be more intense than beam III by about 10%. This circumstance makes it possible to so adjust the intensity of beam II that it lies midway between the intensities I and III. Under these conditions the contrast between I and II will be the same as that between II and III—hence the instrument functions as a contrast photometer. (Fig. 2C).

Fig. 1

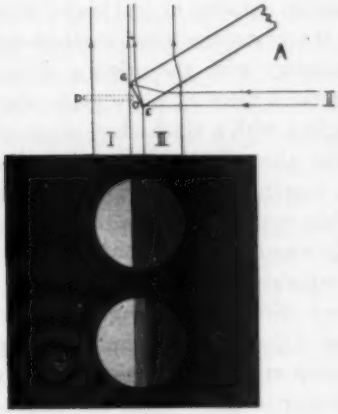


Fig. 2

Tests on the accuracy of setting in making a photometeric match have shown the following results:

1. When the intensity of illumination is fairly great both the contrast and equality of brightness methods yield essentially the same accuracy. The average deviation from the mean of ten settings showed that intensities could be measured to within 0.2 to 0.3 of 1%. This equals the performance of the best procurable photometers.

2. When intensities are low, the contrast photometer yields the more more accurate results.

For the attainment of highest accuracy of setting it seemed desirable to make provisions for a variable contrast. The simplest procedure is that shown in Fig. 2A. Here *D* is a long neutral-tint wedge whose density gradient is perpendicular to the plane of the paper. Since the wedge is thin, its right hand edge *O* is completely occulted by the portion *GE* of the photometer plate. Thus it becomes possible to adjust the position of the neutral tint wedge so that, for any given intensity of light, the least perceptible contrast difference is realized. As previously pointed out,[2] this condition yields double the accuracy attainable by the equality of brightness match.

A somewhat simpler but less effective device involves the use of a thin glass plate, replacing the neutral tint wedge. This glass plate, pivoted at *O*, may be inclined at various angles with respect to the incident beam. The changes in reflection losses will affect, in a limited manner, the contrast. It is realized that any device for changing the contrast will involve a change in the "zero" of the photometer scale. This, however, is not a serious drawback.

Without going into details, it is obvious that the photometer plate may be adapted for use as a flicker photometer by mounting the plate on an oscillating arm, as previously described.[3]

JOHNS HOPKINS UNIVERSITY,
BALTIMORE, MARYLAND,
AUGUST, 1929.

[2] Loc. cit.
[3] Loc. cit.

A BRIDGE GRID RESISTOR AMPLIFIER

By Joseph Razek and Peter J. Mulder

INTRODUCTION

Various forms of vacuum tube bridges, some involving two tube combinations, for the amplification of minute electrical currents and voltages have been employed by recent workers. Brentano[1,2,3] was probably the first to suggest the use of the two-tube bridge, but originally he did not compensate for battery voltage variations. Following him, Wynn-Williams[4,5] added a special type of filament rheostat which, he claimed, made a fundamental difference in operation. Wynn-Williams also suggested the possibility of compensating for plate voltage fluctuations, but found it too difficult and tedious to obtain this compensation experimentally. Marcus[6] eliminated plate voltage. Harris[7] employed separate batteries for each of his tubes. Sharp and Smith[8] used low grid resistors (10-100 megohms) but no compensation. Eglin[9,10] used specially constructed and specially evacuated tubes and added a plate resistance and various grid resistors to the Wynn-Williams bridge.

Of the above papers, only those by Wynn-Williams,[4] by Brentano[2,3], and by Eglin[10] give any mathematical treatment. The sensitivity expression obtained by Wynn-Williams is for the special case of a symmetrical balanced bridge, and the mode of development of his stability conditions is not based on a mathematical deduction from the fundamental equations for his circuit. Furthermore, since Wynn-Williams employed the "free grid" method, no expressions for the grid voltages are involved in his treatment. Brentano gives a very brief treatment of the compensation conditions. Eglin followed the methods of Wynn-Williams, excepting that he inserted a resistance in series with the tube

[1] J. C. M. Brentano, Nature, *108*, p. 532; 1921.
[2] J. Brentano, Phil. Mag., *7*, p. 685; 1929.
[3] J. Brentano, ZS. f. Phys., *54*, p. 571; 1929.
[4] C. E. Wynn-Williams, Proc. Camb. Phil. Soc., *23*, p. 811; 1927.
[5] C. E. Wynn-Williams, Phil. Mag., *6*, p. 324; 1928.
[6] A. Marcus, Phys. Rev., *31*, p. 302; 1928.
[7] D. T. Harris, Jour. of Sci. Instr., *5*, p. 161; 1928.
[8] C. H. Sharp and H. A. Smith, Trans. Il. Eng. Soc., *23*, p. 428; 1928.
[9] J. M. Eglin, Phys. Rev., *33*, p. 113; 1929.
[10] J. M. Eglin, J.O.S.A. & R.S.I., *18*, p. 393; 1929.

in one arm of the bridge to compensate for variations in the plate battery voltage. He also introduced a method of compensating for variations in the grid battery voltage, but he has apparently not been entirely successful in obtaining this compensation experimentally.

The writers[11,12] have independently developed a two-tube bridge in which ordinary commercial tubes and special high grid resistors are employed. These special resistors are adapted to the tubes, both for sensitivity and for compensation, by methods to be presented in this paper.

THEORETICAL DISCUSSION OF AMPLIFIER

The arrangement shown in Fig. 1 is the general two-tube bridge circuit. It is assumed that the symbols are sufficiently well known to need no detailed explanation. The various currents flow as indicated in the figure.

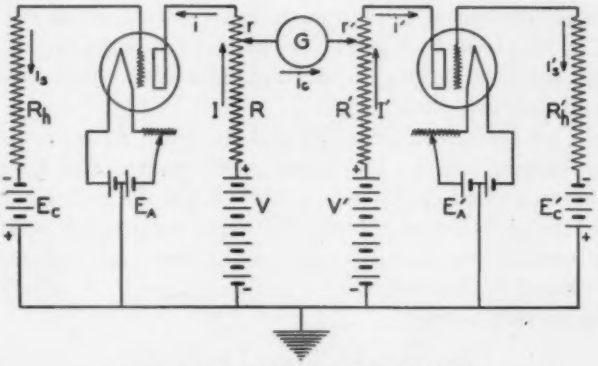


FIG. 1. *Fundamental vacuum tube bridge circuit.*

In order properly to investigate the sensitivity of the circuit and the conditions under which a stable galvanometer zero may be expected, it is necessary to obtain the general expression for the galvanometer current, i_G, as a function of the tube parameters, the resistances, and the values of the various voltages. The circuit constitutes a network, and Kirchoff's Laws of Electrical Networks may be applied. From these follow at once,

$$I = i + i_G \tag{1}$$

$$I' = i' - i_G \tag{2}$$

[11] Preliminary report, P. J. Mulder and J. Razek, Phys. Rev., *33*, p. 284; 1929.
[12] Preliminary report, J. Razek and P. J. Mulder, Phys. Rev., *33*, p. 284; 1929.

$$V-I(R-r)-R_G i_G+I'(R'-r')-V'=0 \tag{3}$$

$$V-I(R-r)-ir-E_p=0 \tag{4}$$

$$V'-I'(R'-r')-i'r'-Ep'=0. \tag{5}$$

Defining the plate current of a vacuum tube by

$$i=AE_a+JE_p+GE_g \tag{6}$$

where

i = plate current of one tube
E_a = voltage applied to filament
E_p = voltage applied to plate
E_g = voltage applied to grid
A = filament temperature function $=\partial i/\partial E_a$
J = plate-to-filament conductance $=\partial i/\partial E_p$
G = mutual conductance $=\partial i/\partial E_g$

The primed symbols refer to the analogous quantities for the second tube. The values of A, J, and G, are not entirely independent of each other, nor constant, but for the small changes in the plate current here considered they may be so taken.

When a grid resistor is used, the grid potential, E_g, differs from the grid bias battery voltage, E_c, by the ohmic drop caused by the grid current flowing through the grid resistor. When the grid is sufficiently negative, the grid current is predominatingly made up of positive ion current, which is very nearly proportional to the plate current, as has been discussed by the writers in a previous paper.[13] As shown there, Eq. (6) may be rewritten

$$i=(AE_a+JE_p+GE_g)/(1-kGR_h) \tag{7}$$

with a corresponding equation for i'. Here "k" is the proportionality factor between the grid and the plate currents.

From Eqs. (1), (2), (3), (4), (5), and (7), it is possible to obtain a single equation for the galvanometer current, i_G, in terms of the tube parameters, the resistances, and the several voltages. This equation is

$$\left[R_G+(R-r)\frac{(1+Jr-kGR_h)}{(1+JR-kGR_h)}+(R'-r')\frac{(1+J'r'-k'G'R_h')}{(1+J'R'-k'G'R_h')}\right]i_G$$

$$=Ki_G=\frac{(1+Jr-kGR_h)V}{(1+JR-kGR_h)}-\frac{(1+J'r'-k'G'R_h')V'}{(1+J'R'-k'G'R_h')}$$

[13] P. J. Mulder and J. Razek, J.O.S.A. & R.S.I., *18*, p. 466; 1929.

$$-\frac{(R-r)GE_c}{(1+JR-kGR_h)}+\frac{(R'-r')G'E_c'}{(1+J'R'-k'G'R_h')}$$
$$-\frac{(R-r)AE_a}{(1+JR-kGR_h)}+\frac{(R'-r')A'E_a'}{(1+J'R'-k'G'R_h')}. \qquad (8)$$

The voltage sensitivity of the circuit, or the change in galvanometer current for a volt change in the grid bias voltage of one of the tubes, can be found by partially differentiating Eq. (8) with respect to E_c. This gives

$$S=\partial i_G/\partial E_c=-G/M= \qquad (9)$$
$$-G$$
$$\frac{RG(1+JR-kGR_h)}{R-r}+1+Jr-kGR_h+\frac{(R'-r')(1+JR-kGR_h)}{(R-r)(1+J'R'-k'G'R_h')}(1+J'r'-k'G'R_h')$$

where M is the whole denominator. This expression differs from our preliminary equation[12] in that it includes the grid resistors and the effect due to the state of vacuum of the tubes. The value of "k" for commercial tubes generally lies between 10^{-6} and 10^{-7}. When used with resistances of 10^9 and 10^{10} ohms, the terms, kGR_h and $k'G'R_h'$, cannot be neglected. Even for specially evacuated tubes, it is doubtful

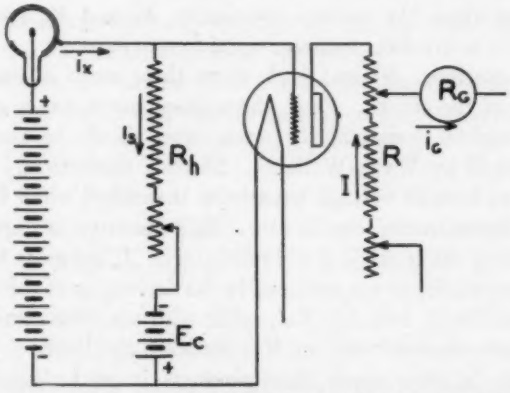


FIG. 2. *Detail of the usual method of attaching a photoelectric cell to the circuit.*

whether "k" can be made so small that the whole product, kGR_h, is negligible. Our sensitivity expression as given above predicts numerical values within one or two percent of the values obtained experimentally.

When the circuit is used to measure small currents, such as the current flowing through a photoelectric cell under the action of a faint

light, an arrangement such as that shown in Fig. 2 is employed. In this case the ratio of the galvanometer current, i_G, to the photoelectric current, i_x, is desired. Since the functions dealt with are all simple, and no singularities are involved,

$$\frac{\partial i_G}{\partial i_x}=\frac{\partial i_G}{\partial E_s}\cdot\frac{\partial E_s}{\partial i}\cdot\frac{\partial i}{\partial i_x} \tag{10}$$

and, as shown in a previous paper by the writers,[13]

$$\frac{\partial i}{\partial i_x}=\frac{GR_h}{1+R_h(1/R_0+1/R_g)-kGR_h} \tag{11}$$

where R_0 is the leakage resistance of the photoelectric cell and R_g is the leakage resistance of the grid of the vacuum tube. By substituting Eqs. (7), (9), and (11) into Eq. (10) we obtain the change in galvanometer current for a given change in photoelectric cell current, or the current sensitivity of the circuit,

$$\frac{\partial i_G}{\partial i_x}=\left[\frac{1-kGR_h}{1+R_h(1/R_0+1/R_g)-kGR_h}\right]\cdot\frac{GR_h}{M}. \tag{12}$$

For cases where the leakage resistances, R_0 and R_g, are very large, the quantity in brackets becomes equal to unity.

These equations, (9) and (12), show three ways of increasing the sensitivity of the circuit. First, the mutual conductance should be as large as possible. Consequently power tubes should be used. This was also suggested by Wynn-Williams. Second, theoretically from these equations an infinite voltage sensitivity is reached when the quantity M, in the denominator, equals zero. This quantity can approach zero only if some of the terms in it are subtractive. If the grids have definite negative potentials, as was assumed in the derivation of the expressions, the products, kGR_h and $k'G'R_h'$, occur with negative signs, as shown. Thereby the numerical value of M is reduced, and hence the sensitivity is increased. In other words, these products, instead of being neglected, become the means whereby high sensitivity is attained. On the other hand, if the grid potentials are positive, the products occur with positive signs, "k" is very much larger, the quantity M is increased, and the sensitivity greatly diminished. Consequently the tubes should be operated with the grid potentials negative. Even though M may approach zero in value, the sensitivity is not infinite. It is then limited by the quantities of the second order of smallness which have been

neglected throughout the derivation. But practically it does become very large. Third, for a given value of the voltage sensitivity, the current sensitivity is directly proportional to the magnitude of the grid resistor it is posssible to use.

In practice it is found that the galvanometer reading may become unsteady when attempts are made to detect changes of plate current of less than a few ten thousandths of itself. This unsteadiness is caused partly by fluctuations in the various batteries in the circuit. An ordinary balanced Wheatstone's bridge is independent of fluctuations in the battery voltage, and it should be possible to adjust a vacuum tube bridge to approach that condition.

Since Eq. (8) shows that i_G is a function of V, V', E_a, E_a', E_c, E_c', and since the resistances and the tube parameters are constant in time, the total derivative of i_G with respect to time can be written

$$\frac{di_G}{dt}=\left(\frac{\partial i_G}{\partial V}\right)\frac{dV}{dt}+\left(\frac{\partial i_G}{\partial V'}\right)\frac{dV'}{dt}+\left(\frac{\partial i_G}{\partial E_c}\right)\frac{dE_c}{dt}$$
$$+\left(\frac{\partial i_G}{\partial E_c'}\right)\frac{dE_c'}{dt}+\left(\frac{\partial i_G}{\partial E_a}\right)\frac{dE_a}{dt}+\left(\frac{\partial i_G}{\partial E_a'}\right)\frac{dE_a'}{dt}. \qquad (13)$$

The various time derivatives of quantities in this equation can be taken to represent the fluctuations in those quantities.

Taking the required partial derivatives from Eq. (8), and substituting these into Eq. (13), we obtain the general compensation expression,

$$\frac{di_G}{dt}=\frac{1}{K}\left[\frac{(1+Jr-kGR_h)}{(1+JR-kGR_h)}\frac{dV}{dt}-\frac{(1+J'r'-k'G'R_h')}{(1+J'R'-k'G'R_h')}\frac{dV'}{dt}\right.$$
$$-\frac{G(R-r)}{(1+JR-kGR_h)}\frac{dE_c}{dt}+\frac{G'(R'-r')}{(1+J'R'-k'G'R_h')}\frac{dE_c'}{dt}$$
$$\left.-\frac{A(R-r)}{(1+JR-kGR_h)}\frac{dE_a}{dt}+\frac{A'(R'-r')}{(1+J'R'-k'G'R_h')}\frac{dE_a'}{dt}\right]. \qquad (14)$$

Since the coefficients of the voltage time derivatives can never be equal to zero, this equation shows that it is impossible to obtain compensation when using separate batteries. However, in the case of common filament, common plate, and common grid batteries, compensation for all battery voltage fluctuations may be obtained if the two tubes are operated at points where all their characteristics are identical in pairs, or where they have certain equal ratios, nearly unity. It may be possible to realize this condition experimentally, but it is extremely difficult

and tedious. Consequently some other solution, involving a smaller number of relations, is desirable.

EXPERIMENTAL ARRANGEMENT AND USE OF AMPLIFIER

Any arrangement in which the voltage time derivatives of Eq. (14) are related to each other should simplify the process of obtaining compensation. One arrangement for this purpose consists in using a single battery for the filament, the plate, and the "C" bias voltages. It is possible to supply both filaments from the common battery by making them a part of a potential divider from which the plate, and the "C" battery voltages are taken. Operating points for such a circuit can be found at which a considerable change in battery voltage will not cause a noticeable change in the galvanometer reading. Although drifts were found to be absent, the galvanometer was still subject to sudden irregularities. The explanation of this lies in the fact that the filament lags behind the plate and the grid circuits in responding to the changes

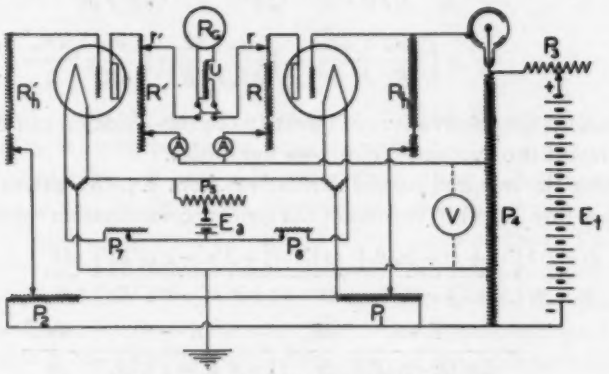


FIG. 3. *The bridge grid resistor amplifier circuit.*

in voltage. Consequently, it was found best to use a good storage battery for the filaments, and another large battery with an appropriate potential divider for the plate and the grid circuits.

The actual circuit as used by the writers in connection with a photoelectric cell is shown in Fig. 3. It was found very convenient to use the universal shunt, U, with the galvanometer. In the grid circuit of each tube are placed the high resistances, R_h and R_h', made of xylol and alcohol sealed in glass tubes as described by the writers.[13] The voltage applied to the grid resistors can be adjusted by the potential dividers, P_1 and P_2. These are connected in parallel, one end to the grounded

point on the main potential divider P_4 and the other to the point of maximum negative potential.

The plate circuit, the grid circuit, and the anode of the photoelectric cell are all supplied by the common battery E_t, across which the main potential divider P_4 and a rheostat P_2 are connected. The value of P_4 was chosen so that a current of about one quarter of an ampere is taken from the battery E_t. If desired, a voltmeter can be placed across part of the potential divider, as shown, to indicate the voltage impressed upon the bridge for the various settings of the rheostat P_2. The rheostats, P_3 and P_5, allow small changes to be made to simulate variations in the batteries, E_t and E_a, respectively. The several rheostats and potential dividers are provided with dials, so that the various settings can be recorded and repeated as desired.

Most of the precautions necessary for the successful operation of this arrangement are the same as those mentioned by Wynn-Williams,[4,5] Eglin,[10] and Brentano,[2,3] for their somewhat similar circuits. One requirement deserves additional emphasis, that is, the necessity of extremely high insulation of the grid and the plate circuits. The arrangement of the parts should be such that the only materials in, contact with the grid and the plate circuits are glass and sulphur or their equivalent. The tubes themselves are selected for high internal insulation. The grid and the plate prongs of the tubes should be insulated from the bakelite base by drilling out the latter and supporting the prongs on sulphur poured into the press.

COMPENSATION OF CIRCUIT

The use of a single battery for the plate and the grid circuits of both tubes, and of a common battery for the filaments, simplifies the determination of the points at which the circuit should be operated. Mathematically, this can be expressed by letting

$$V=\alpha E_t \qquad V'=\alpha' E_t \tag{15}$$

$$E_c=\beta E_t \qquad E_c'=\beta' E_t \tag{16}$$

$$E_a=\gamma E_a \qquad E_a'=\gamma' E_a. \tag{17}$$

By substituting the respective time derivatives obtained from these Eqs. (15) to (17) into Eq. (14) the compensation equation for the circuit as used is obtained.

$$K\frac{di_G}{dt}=\left\{\left[\frac{1+Jr-kGR_k}{1+JR-kGR_k}\right]\alpha-\left[\frac{1+J'r'-k'G'R_k'}{1+J'R'-k'G'R_k'}\right]\alpha'\right.$$

$$-\left[\frac{G(R-r)\beta}{1+JR-kGR_k}\right]+\left[\frac{G'(R'-r')\beta'}{1+J'R'-k'G'R_k'}\right]\Bigg\}\frac{dE_t}{dt}$$

$$-\left\{\left[\frac{A(R-r)\gamma}{1+JR-kGR_k}\right]-\left[\frac{A'(R'-r')\gamma'}{1+J'R'-k'G'R_k'}\right]\right\}\frac{dE_a}{dt}. \qquad (18)$$

To test these two coefficients for zero value by numerical substitution would be highly unsatisfactory. It would be very difficult to determine the values of the quantities involved to a sufficient degree of accuracy. Furthermore, there are undoubtedly quantities of the second order of smallness, which have been neglected in this derivation, among which certain relations will also have to be satisfied.

The circuit itself offers an ideal means of testing how well all the required conditions have been met. The detailed procedure in obtaining compensation depends somewhat upon the apparatus available. If a sensitive galvanometer (about 10^{-11} amp/mm) is available, the curves showing the relation between grid positive ion current and plate current are obtained to determine the values of "k." These will generally differ, as they depend on the quantity of gas present in the tubes. It is desired that the effective mutual conductances of the tubes be approximately the same. This is accomplished by appropriately adjusting the value of the grid resistor for each tube. Neglecting the effect of the plate resistance, the effective mutual conductance

$$G_e=G_e'=G/(1-kGR_k)=G'/(1-k'G'R_k') \qquad (19)$$

from which it can be readily shown

$$1/G-1/G'=kR_k-k'R_k'. \qquad (20)$$

Knowing the values of the mutual conductances, G and G', and of "k" and "k'", appropriate values of R_k and R_k' are chosen to satisfy Eq. (20).

If a galvanometer of the high sensitivity mentioned in the previous paragraph is not available, it is still possible to make the effective mutual conductances approximately equal by somewhat altering the procedure. A group of resistors is made by sealing mixtures of xylol with different proportions of alcohol in glass tubes. The "C" battery voltage-plate current characteristic of the tubes with each resistor, together with the normal characteristic with no resistor, are obtained and plotted as shown in Fig. 4. At the value of plate current at which it is expected to operate, a horizontal line is drawn. The intercept AB, referred to the

scale of volts, is the drop resulting from the flow of the grid positive ion current through the grid resistor. As described by the writers pre-

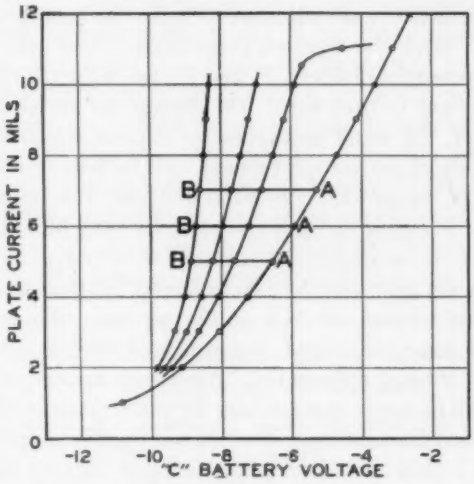


FIG. 4. *"C" battery voltage-plate current characteristics for various values of grid resistor.*

viously,[13] the positive ion grid current i_g is nearly proportional to the plate current i, and we may write

$$i_g = ki \tag{21}$$

and therefore

$$AB \text{ in volts} = R_h i_g = R_h k i. \tag{22}$$

The value of the quantity, $R_h k$, for the resistor used with the particular tube can be found at once by dividing the intercept AB, expressed in volts, by the plate current i. The value of the mutual conductance, which is the slope of the normal "C" battery voltage-plate current curve at the operating point A, is found for both tubes. Those values of grid resistors which satisfy Eq. (20) are used with the respective tubes.

To facilitate the final adjustment, it is possible to make the grid resistor in two portions connected in series; one, fixed, of about 90% of the total value, the other, an adjustable resistor. The latter can conveniently be made of glass tubing of about three millimeters bore with a wire sealed in at one end. The tube is mounted vertically, and filled with pure glycerine. A rod is pushed through a stopper for the upper

contact. Such a resistor about 15 cm long will have a maximum resistance of about 175 megohms.

After the circuit is completely assembled, the two variable portions of the plate resistances are adjusted to make the total plate resistance nearly equal. With the filament rheostats at some arbitrary setting, the grid bias potential dividers, P_1 and P_2, are adjusted to give the desired plate current in each tube. On closing the switch in the galvanometer circuit, the small galvanometer current which will generally flow due to lack of perfect adjustment, can be balanced out by readjusting either of the grid bias potential dividers. Fine adjustment may be secured by changing the galvanometer tapping points, r and r'.

By changing the setting of P_5, filament battery fluctuation is simulated. Curves are drawn of the galvanometer readings against the settings of P_5 for various settings of the separate filament rheostats. Points of zero slope are desired, and it is soon evident whether or not that condition is being approached. After such zero slope points have been found, the filament rheostats are set at the readings corresponding to the points, and filament compensation has been accomplished.

The circuit is then tested for plate and grid battery compensation. The procedure is the same as before, except that the curve is plotted with galvanometer readings against the settings of the rheostat P_3 in the main battery circuit. If the grid resistors have variable portions, changes in their values can be made until the curve shows a maximum or minimum. As an alternative, the values of the plate resistors, R and R', can be changed. It is generally most convenient to make an approximate setting with the grid resistors and the final adjustment by changing the plate resistors.

However, when the grid or the plate resistors are changed, the filament battery compensation has been somewhat upset. Consequently if the greatest possible degree of stability is desired, the procedure is again repeated until a slight change in either P_3 or P_5 will leave the galvanometer reading unchanged. Samples of the curves obtained during the determination of the compensation points are shown in Fig. 5.

Such curves should be drawn. They may have sharp maxima or minima, and a single definite change in voltage may cause a change from a reading on one side of the peak to an equal reading on the other side. The writers have obtained these effects. For such definite changes the galvanometer gives a kick while the is change being made. The plotted curve shows the reason. In other words, single definite changes in voltage do not establish the compensation condition. But continously

variable rheostats, changed slowly, together with a curve of the readings, will show the desired points of operation.

The value of "k" seems to change very slowly with time, in a manner which probably depends upon the use of the tube. Consequently the compensation settings for the circuit will change and the procedure of finding the best operating points has to be repeated from time to time. However, this process requires only a quarter, to a half hour.

A change in "k" also alters the voltage sensitivity. For easy recalibration, a definite voltage, taken from a separate cell and a potential divider permanently attached in one of the grid circuits between the potential divider, P_1 or P_2, and the grid resistor, may be cut in or out with a switch. Or a more elaborate potentiometer may be substituted

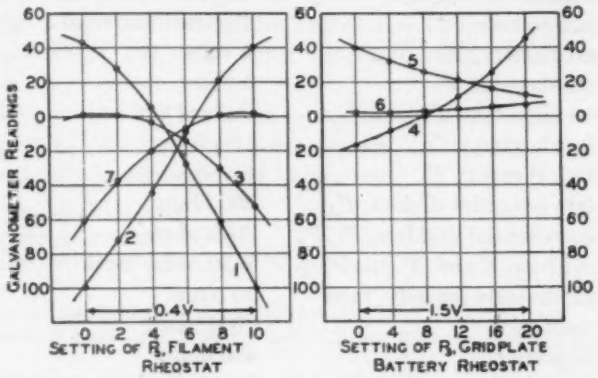


FIG. 5. *Sample curves obtained during the determination of the operating points for the circuit. The curves were obtained in the order in which they are numbered.*

for P_1 or P_2, and a null method may be employed. This is equivalent to a calibration for every reading.

After the operating points for the desired degree of stability have been found, the circuit is ready for use and the actual procedure beyond this point depends upon the use to which the circuit is put. If it is used to read photoelectric currents, the galvanometer can be made to read zero with no light admitted to the cell. When light is admitted, the galvanometer will deflect, and the amount of the deflection depends on the intensity of the light admitted. For comparison of light intensities, it is possible to balance the circuit while light from one source is admitted to the cell. On admitting light from another source the galvanometer deflection will be a measure of the difference in intensities. In

this way slight differences in intensity can readily be detected. Methods of using this circuit for other purposes immediately rise in the mind of the experimenter.

TABLE OF DETAILS OF AMPLIFIER

The following table gives the details of the parts of the Bridge Grid Resistor Amplifier as used by the writers for the measurement of photoelectric currents.

Vacuum tubes,	2 Cunningham CX 312 A
Plate voltage,	100 volts
Filament current,	0.20 amps approx.
Plate current,	5 to 7 milliamperes
Galvanometer sensitivity	1.5×10^{-9} amp/mm
Galvanometer shunt	Decimal universal
Filament battery, E_6	4 volts
Filament rheostat, P_5	1 ohm
Filament rheostats, P_6 and P_7	6 ohms
Grid-plate battery, E_4	190 volts
Grid-plate rheostat, P_3	6 ohms
Grid-plate potential divider, P_4	800 ohms
"C" bias potential dividers, P_1, P_2	3000 ohms
Plate resistors, R and R', made up	1430 ohms total
Potential dividers for galv. taps	30 ohms
Fixed resistance	1000 ohms
Variable portion	400 ohms
Voltage sensitivity on 1/10 shunt	1×10^{-8} volts/mm
Current sensitivity on 1/10 shunt	7×10^{-18} amp/mm

CONCLUSION

This bridge grid resistor amplifier possesses certain definite advantages over others that have been proposed.

1. It employs ordinary commercial tubes, selected only for high internal insulation.

2. It allows these tubes to be operated at any points whatever on their characteristics.

3. It makes use of the ionization currents,[10] to obtain high sensitivity.

4. It allows complete and readily attainable compensation for all battery voltage fluctuations.

Although the capacity of the grid of a vacuum tube is very small, yet when it is combined with the high value of the grid resistors here used,

a time constant[14] of a few thousandths of a second is obtained for the grid circuit. This limits the use of this type of amplifier to low frequencies.

In connection with a photoelectric cell, the writers[12] have used this amplifier to obtain curves showing the intensity of several lines of the mercury arc spectrum as functions of the power used in the arc. A complete curve for each line, showing twenty-four readings, was obtained in six minutes. Spectral distribution curves of the light diffusely reflected from opaque objects, and of light transmitted through various liquid samples, have also been obtained. With appropriate additions, the circuit with a photoelectric cell has been used as an excellent densitometer by Dr. W. R. Wright, of Swarthmore College.[15] Obviously a bridge amplifier of this sort may be used to replace the quadrant electrometer in many experiments. Many other uses, as for ionization chamber, piezoelectric, pH, and other[16] measurements, readily suggest themselves.

In conclusion the writers desire to express their appreciation to Dr. C. B. Bazzoni, director of graduate research at the Randal Morgan laboratory, for his guidance and suggestions.

RANDAL MORGAN LABORATORY,
UNIVERSITY OF PENNSYLVANIA,
PHILADELPHIA, PENNA. JUNE 10, 1929.

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[15] See also C. E. Hesthal and G. R. Harrison, Bull. Am. Phys. Soc., *4*, No. 3, p. 9; June, 1929.

[16] C. J. Davisson and L. H. Germer, Phys. Rev., *33*, p. 760; 1929.

A GAS-FILLED X-RAY TUBE OF SMALL DIAMETER AND LARGE POWER CAPACITY

By Russell H. Varian

In connection with some experiments on the Compton effect[1] it was found necessary to construct a tube, having reasonably large power capacity, with a thin window as near as possible to the focal spot. Several gas-filled tubes having these features have been described. They are of two general types, that designed by Muller and Shearer,[2] and the Siegbhan-Hadding type.[3] The tube here described, which was developed after considerable experimentation, combines many of the desirable features of both types. Like the Muller-Shearer tube it can be made entirely of materials available in any laboratory and it will run as a self-rectifying tube at low power input. Like the Siegbahn-Hadding tube it operates steadily on a very large power input of rectified current. The distance from the focal spot to the aluminum windows is only about 6 mm. which is considerably less than that of tubes previously described.

This tube has been run for long periods on mechanically rectified current at 40 kv and 40 ma, the water cooling system of the cathode being used as a ballast resistance. Run in this way its operation is considerably more stable with respect to changes in the line voltage than a Coolidge tube operated with a filament transformer on the line. In some cases it has run for as long as eight hours without requiring adjustment of the vacuum and without a change of current greater than ± 2 ma. The tube has also operated at 50 kv and 30 ma. Whether it will operate at higher voltages or greater power is not known, because neither was available for making tests. It may be that the power capacity can be greatly increased by cooling the thin windows with an air blast.

[1] R. H. Varian. pp. 351 this issue.

[2] X-Rays and Crystal Structure, W. H. and W. L. Bragg. E. A. Owen and G. D. Preston, Journ. Sci. Inst., *4*, pp. 1–3; 1926. S. H. Piper, Journ. Sci. Inst., *6*, p. 105; 1929. W. Band and A. J. Maddock, Journ. Sci. Inst., *6*, pp. 160–63; 1929. L. F. Curtis, J.O.S.A. and R.S.I., *16*, pp. 68–70; 1928.

[3] Siegbahn, Spectroscopy of X-Rays, p. 35. A. Hadding, ZS. f. Phys. *3*, pp. 369–371; 1920. C. Leiss ZS. f. Phys., *41*, pp. 395–396; 1927. H. Ott, Phys. Zeits. *27*, pp. 598–599; 1926.

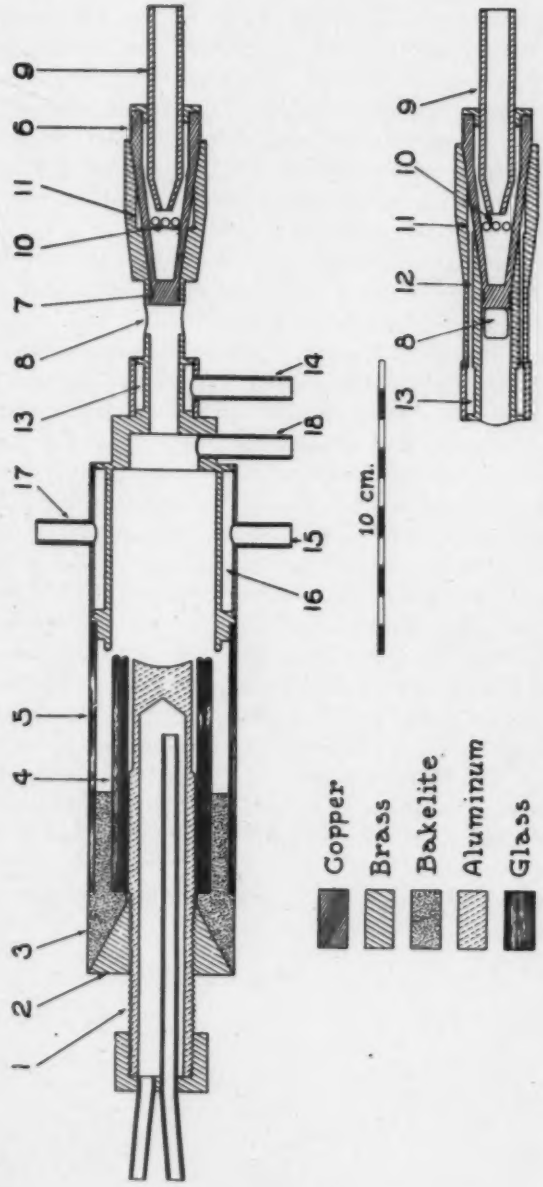

FIG. 1. *Cross section of gas filled x-ray tube.*

The tube is shown in cross section in Fig. 1. The cathode assembly consists of the water-cooled concave aluminum cathode 1 and the brass cone 2 through which it is screwed. The screw serves to readjust the cathode to its best position after pitting has made it necessary to refinish the concave surface. The thread is made airtight with sealing wax. Cone 2 is seated in bakelite unit 3, the joint being made tight with lanolin. The pyrex tubes 4 which serve as shields and the outer pyrex tube 5 are attached to unit 3 with sealing wax.

The target is the flat end of copper cone 6. The conical joint is made tight with sealing wax which is prevented by groove 7 from flowing out onto the target. The rest of the anode assembly is of brass. With the exception of the outlet tubes and parts of the water jackets it was turned from a single piece of material. It is attached to tube 5 with sealing wax. Two flat sides were milled on this unit and a transverse hole was drilled and then filed square as shown at 8. A strip of aluminum 0.04 mm thick was wrapped around the unit at this point and fastened with wax. This provides two thin windows on opposite sides of the tube and equidistant from the focal spot. Water enters nozzle 9 and after cooling the target it flows thru holes 10 into recess 11, then thru six longitudinal holes 12 past the thin windows to jacket 13 which contains a baffle (not shown) to make the water flow around 13 properly before leaving thru outlet 14. From 14 it flows thru a rubber tube to 15 around jacket 16 and out thru 17. The exhaust pump is attached at 18.

The tube was exhausted by means of a mercury diffusion pump and a fore-pump. No liquid air was used. The vacuum was controlled by a bypass around the diffusion pump as described by the Braggs.[3] It consisted of a piece of pressure tubing and a nicely adjustable clamp. A roughly adjustable leak of some sort must be provided to control the fore pump vacuum.

The writer wishes to thank Mr. B. Stuart for his cooperation in the construction of this tube.

PHYSICS DEPARTMENT,
STANFORD UNIVERSITY,
PALO ALTO, CALIFORNIA.

A NOTE ON A STATIC MACHINE WITH PYREX INSULATION

By A. W. Simon

The remarkable insulating properties of Pyrex glass, more particularly the fact that its insulating properties are unimpaired by atmospheric conditions, made it seem desirable to determine its value as the insulating material in an ordinary static machine, As is well known the insulation in such machines has usually consisted of glass which is coated with shellac to give it better insulating properties. However even with this precaution such machines show a great sensitivity to atmospheric moisture, failing almost completely on damp days. Also the shellac coating gradually deteriorates or accumulates a coating of dust, making it necessary to remove the shellac coating entirely and to replace it with a new one. With these ideas in mind an experiment was tried in which a small static machine of the Wimshurst type with 14 in. plates was rebuilt with the substitution of Pyrex glass as the insulating material. The experiment was very successful: the rebuilt machine operated as well on damp days as on dry days and furthermore could be readily cleaned when dust settled on the insulating parts.

Insulation is made use of in an ordinary static machine, as is well known, in three places; namely (1) the rotating discs (2) the supports for the collecting combs and (3) the condensers.

The discs of the old machine were replaced with plain (uncoated) Pyrex discs made of selected sheets (selected with a view to planeness) of Pyrex sheet glass. The insulating supports for the collecting combs were replaced with heavy walled Pyrex tubing. The condensers were replaced with Pyrex "phosphorous" Erlenmyer flasks, the outer coating being tinfoil and the inner a coating of copper which was electro-plated on a (chemically-plated) coating of silver. The minimum creepage distance was made the same on the three sets of insulators.

The resulting machine gave a very heavy and high voltage spark, measurement with a large sphere gap indicating a voltage of about 75 kv. Furthermore its action was very little influenced by atmospheric conditions; it operated very successfully on days when there was a heavy rain falling outside and the windows were open.

The machine as rebuilt was fitted with only eight sectors in place of the original thirty-two. This somewhat impaired its self-exciting properties but very likely increased the voltage of the machine on account of the fact that brushing from sector to sector is avoided.

With Pryex glass, when the discs become dusty, it was necessary only to wipe off the dust to restore the machine to its original efficiency.

RESEARCH LABORATORY,
TENNESSEE COAL, IRON & RAILROAD CO.,
(SUBSIDIARY OF UNITED STATES STEEL CORP.)
BIRMINGHAM, ALABAMA.

Hugo Dingler. Das Experiment; sein Wesen und seine Geschichte. III+263 pp. Verlag Ernst Reinhardt, München, 1928. Price 8.80 marks.

It is a more or less generally accepted view that the present progress of Science is to a large extent, if not solely, due to the development of the experimental method. Through the experiment "Nature answers to the questions of the investigator" and thus gives the most direct evidence of any scientific truth. The field of application of the experimental method seemed at first almost unlimited, and Gauss, as well as Lobachevsky, made even attempts to decide by geodetic, respectively astronomic, measurements (in other words, by experiment) whether the geometry of our space was Euclidean or not. The great Henri Poincaré was the first to draw attention to certain important limitations of the experimental method. In particular, he pointed out that the question of the geometry of our space cannot be decided experimentally. If, for instance, he says, we would find for some stars negative parallaxes, we can interpret this fact either by saying that our space is non-Euclidian, or that in an Euclidian space the rays of light do not follow straight lines. He went even further and declared that the laws of mechanics cannot be considered as established experimentally. For instance, if we assume that the gravitational attraction follows a different law, than that of the inverse squares, we still could obtain the correct planetary orbits, by changing the second law of motion, that is, by assuming a different relation between force and acceleration, than that of simple proportionality. According to Poincaré, the laws of geometry and of dynamics are not empirical laws but arbitrary conventions, which are particularly distinguished from other possible conventions by their simplicity. These ideas have received their further development by some physicists in connection with the advent of the Relativity Theory. In particular, the reviewer has shown six years ago, by an analysis of those experiments which are usually considered as lending an experimental support to the Relativity Theory, that even if the results of those experiments

would have been just opposite to what they actually are, they still could be interpreted from the relativistic point of view. The conclusion is therefore made that the postulates of the Relativity Theory about time and space, are also not empirical, but conventional. Facing such a situation, we naturally must ask whether the failure of the experimental method is limited only to the above mentioned fields of geometry and dynamics. This leads to a more general question, namely, as to whether the true nature of the experiment is just as simple, as it has been assumed hitherto, that is as to whether an experiment is merely a "questioning of Nature." This important problem is dealt with in Dingler's book, which, it must be said at once, is only at present the last link in a series of other important publications on similar subjects. The nature of the problem involves it that the treatment is not merely physical but to a great extent a philosophical one. The author starts with such fundamental questions as the nature of logics, and discusses the recent attempts to construct a "non-Aristotelian logic." He shows that if we require from the rules of logics definiteness (Eindeutigkeit), a non-Aristotelian logic becomes impossible. Passing to the nature of the experiment, the author develops further in detail the analysis of the nature of geometry. He emphasizes particularly the circumstance, that in every experiment we use certain standardized apparatus, which must possess certain properties of constancy. Our standard of constancy ultimately is based on the constancy of rigid bodies. What is a rigid body? How is it defined? The author shows by a detailed analysis, that all empirical definitions of the rigid body, hitherto proposed, are inadequate and lack of definitness (Eindeutigkeit). The only adequate definition which, by the way, even if not clearly formulated, has always been used subconsciously, is this, that a rigid body is such a body which follows the rules of the Euclidean geometry. In making, in manufacturing, rigid rods and scales, we always use the above definition as a criterion of their rigidity, and interpret the deviations as imperfectness of the corresponding rod or scale. From this point of view the impossibility of detecting experimentally any deviation from Euclidean geometry in our space becomes particularly clear. Perhaps the author does not emphasize sufficiently that purely logically we could define a rigid body as one, which follows the rules of any of the non-Euclidian geometries and thus find our space non-Euclidian. It must, however, be agreed that such a step would mean much more than a mere revolution of scientific views. It would require a radical modification in the interpretation of our every day experience. A similar analysis is made further of the laws of dynamics, with similar results. From all the discussion there appears an essentially new view on the nature of the experiment. As seen on the above example of geometry, and as shown by the author for other fields of science, the human mind *creates* certain abstract forms and relations and we then

seek to construct in reality these abstract forms and relations by means of a series of manual manipulations. From a simple "questioning of Nature" the experiment becomes a creative procedure of constructing in the external world of those abstract relations. On hand of Dingler's discussion it becomes particularly clear, how large a part is played in every experiment by the *interpretation* and to how little an experiment amounts without the proper interpretation.

We cannot say that every argument in the book is beyond any possible criticism. But the author himself calls his book a "pioneering one," and no one will ever expect a pioneering work to say the last word. Dingler's remarkable productivity justifies the hope that in the near future, all the unevenness, which is naturally inherent to the treatment of such difficult questions, will be smoothened, and that we will possess a perfect in all respects "theory of the experiment." We may only repeat the words which R. Seeliger wrote about a previous book of Dingler: "Every not quite non-philosophically inclined scientist, and in particularly all physicists should read this book."

N. RASHEVSKY

TRANSMISSION IN THE ULTRAVIOLET OF PARAFFIN COATED CLOTH

By Vladimir P. Lubovich and Margaret McC. Maltbie

With increasing interest in the use of ultraviolet radiations in therapy and in animal husbandry, and with greater and greater use of these radiations in chemical, physical, and biological laboratories, there has come a demand for inexpensive and easily obtainable substitutes for fused quartz. In the past few years many special glasses have been developed, the best of which (corex D) transmits to approximately 2600A.

The materials considered in this investigation are glass substitutes consisting of white cloth coated with what is apparently paraffin. Though they are intended by their manufacturers for use in animal husbandry, the present investigation has led to the conclusion that they may also be used in the laboratory.

Two sources of ultraviolet and visible radiation were used. To obtain a continuous spectrum a carbon arc, running on dc (110v, 10 amp) was used. It was found, as noted by Coblentz,[1] that cored electrodes gave a steadier arc. The highly incandescent anode was focused on the slit of the spectrograph. A line spectrum, for more convenient measurement of limits, was obtained from a small quartz mercury arc (Cooper Hewitt "Labarc"). When the polarity was such that the lower part of the arc was positive, it ran without flickering, but extinguished itself after about 20 minutes; therefore, for long exposures it was necessary to reverse the polarity, which gave a flickering arc of less intensity that would, however, burn indefinitely. Twenty-two mercury lines were indentified and served to measure the limits of transmission.

The limits of transmission were determined photographically. While this method is inferior to measurement with a thermopile in that it gives only a rough idea of the amount of light transmitted, it has the advantage of showing the extreme limit, where the radiation is not sufficiently great to produce an appreciable effect on the thermopile. The photographs were taken with a Hilger E31 (small quartz) spectrograph, using Eastman Process plates. At first plates oiled with light

[1] Spectral Characteristics of Light Sources and Window Materials Used in Therapy, W. W. Coblentz; Trans. I.E.S., *23*, p. 247; 1928.

petroleum oil (Nujol) were used, as suggested by Harrison,[2] but this method was discarded because the increased sensitivity of the plate to ultraviolet in the region under consideration was not sufficiently great to justify the time spent in oiling the plate and in removing the oil before development.

Two types of photographs were taken, namely, the continuous spectrum of the carbon arc, passing through a filter of the material to be examined, and the mercury arc spectrum through a similar filter. It was hoped that from the former type it would be possible to determine the transmittance, by comparing the intensity of the light transmitted

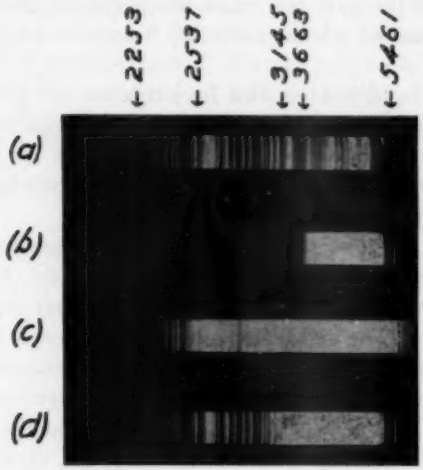

FIG. 1. *Spectrum of quartz mercury arc (a) without filter, 1 min. exp: (b) through ordinary window glass, 1½ min. exp: (c) through Flex-o-glass, 100 min. exp: (d) through paraffin coated cheesecloth, 50 min. exp.*

through the photographic image with the intensity of that transmitted through the image of the spectrum without filter. However, the light so transmitted was not of sufficient intensity to give reliable measurements so the effort was abandoned.

An approximate determination of the percentage of visible light transmitted was made by measuring with a Lummer-Brodhun photometer the intensity of light transmitted through samples of the materials and comparing it to the intensity of the incident light, without filter.

[2] Photographic Sensitometry with Fluorescent Oils, G. R. Harrison; J.O.S.A. & R.S.I., *11*, p. 113; 1925.

The photograph reproduced in Fig. 1 shows the spectrum of the quartz mercury arc photographed without filter, and also through ordinary window glass, Flex-o-glass, and cheesecloth which had been coated with paraffin. The materials investigated were Flex-o-glass and two grades of Glass Cloth, designated here as *A* and *B*. The results obtained with each will be taken up separately. Flex-o-glass is manufactured by the Flex-o-glass Manufacturing Company of Chicago. The material weighs approximately 275 grams per square meter, and the cloth basis is woven with about 20 fine threads to the centimeter. As determined by the photometric method described above, the amount of light transmitted is about 11%.

This material was studied briefly by Coblentz,[1] who gives a graph showing the percentage of radiation transmitted between 4358A and 2537A, as determined with the thermopile. By the photographic method we were able to study the region of wave length shorter than 2537A. When the source used was the carbon arc, a 10 minute exposure through the sample of Flex-o-glass gave a continuous spectrum to approximately 2800A, and lines to about 2425A. Using the mercury arc, we obtained after a 100 minute exposure through the filter lines to 2253A. In all probability the failure to obtain lines between 2425A and 2253A with the carbon arc is due to the fact that the intensity of this source itself falls off rapidly at wave lengths shorter than 3000A.

Glass Cloth A, manufactured by Turner Brothers, Bladen, Nebraska, weighs approximately 250 grams per square meter. The threads, which are much coarser than those used in Flex-o-glass, run about 15 to the centimeter. It transmits about 7% of the incident light. With the carbon arc it transmitted continuous spectrum to approximately 3100A, and lines slightly shorter than 2537A. The last mercury line photographed through this material was 2302A.

Glass Cloth B, manufactured by the same company, weighs about 245 grams per square meter. The threads, somewhat finer than those in Glass Cloth A, run about 17 to the centimeter. Photometric measurements indicate that about 8% of the incident light is transmitted. It transmitted the continuous spectrum of the carbon arc to about 3300A, and the last carbon line photographed was around 2900A. When the mercury arc was used as source, lines to 2354A appeared.

A further test was made with a sample prepared in the laboratory. A piece of white cheesecloth was stretched taut on a wooden frame and dipped into melted paraffin at about 150°C. It was then removed and

the paraffin allowed to harden, after which the frame was suspended above the melted paraffin until the wax on the material had melted and all but a thin uniform coating had dropped off or distilled away. The whole paraffin bath was then removed from the heater and allowed to cool until the paraffin on the cloth was solid.

The material thus prepared weighs approximately 300 grams per square meter. It runs about 16 threads to the centimeter, but they are so much finer than those in either sample of Glass Cloth that the major part of the material consists solely of a thin paraffin layer. As might be expected, the transmission is higher than that of the commercial materials; namely, about 19%. In determining the limit of transmission of this sample, only the mercury arc source was used. The exposure was 50 minutes (only one half of that given through the other filters) and the spectrum to 2253A was photographed, though not so distinctly as with a 100 minute exposure through Flex-o-glass.

As pointed out by Coblentz,[1] many of the glasses which transmit ultraviolet when new partially lose this property after a few hours of exposure. This phenomenon is thought to be due to the conversion by the ultraviolet rays of ferrous iron, present in the glass as an impurity, to the ferric state. Obviously, the glass substitutes under investigation should show no such effect.

Samples of Flex-o-glass and of both grades of Glass Cloth were exposed to the weather, including a certain amount of bright sunlight, for two weeks. Other samples of the same materials were exposed to the radiation from a powerful Gallois quartz mercury arc for approximately 200 hours. The limits of transmission of these sample were then found in the same way as those of the unexposed materials. Without exception, it was found that the intensity of the short wave-length light transmitted was increased by exposure to the sun, and still further increased by exposure to the lamp.

Using the mercury arc as source, the following results were obtained. No new lines appeared through Flex-o-glass which had been exposed to solar radiation, but the photograph taken through the sample which had been exposed to the lamp showed a line at 2228A and what may be one at 2209A. Glass Cloth *A* showed no new lines through either sample. Glass Cloth *B* gave the line at 2303A with both solarized filters. The results obtained with the carbon arc source were analogous.

It would seem probable that both the increased intensity and the slight increase in the limits are due to sublimation of the paraffin. The

appearance of additional lines is easily explained when we remember that transmission is never cut off sharply at a given point, but drops to a fraction too small to register on the photographic plate.

In general, the results of the investigation may be summed up as follows. The materials all transmit to within 50A more or less than 2300A. In the visible region they transmit on the average less than 10% of the incident light. Our photographs lead us to conclude that this percentage holds down to about 2537A (a 5 minute exposure through arc solarized Glass Cloth *B* gave this line), beyond which it falls off rather rapidly.

As Coblentz[1] has pointed out, in therapy it is worth while, if one intends to use ultraviolet transmittting materials, to invest in a good grade of glass which is transparent between 3200A and 2900A (the portion of the solar spectrum cut off by ordinary glass). On the other hand, in animal husbandry, where large quantities of such material are necessary and where the danger of breakage is comparatively great, these glass substitutes should prove useful.

Furthermore, it would probably be profitable to use them in laboratory work where a waterproof substance is desired which will transmit to about 2300A, and where high percentage transmission is not a factor. In this case best results would probably be obtained by coating a loosely woven white cotton[2] material with a very thin layer of paraffin. Such a material would have less strength than the commercial products, and would probably be unsuited for outdoor use, but its transmittance would be considerably higher.

It is the authors' wish to thank the Flex-O-Glass Manufacturing Company, of Chicago, and the Turner Brothers, of Bladen, Nebraska for free samples of Flex-O-Glass and Glass Cloth respectively.

UNIVERSITY OF COLORADO,
BOULDER, COLORADO. (V. P. L.)

SWARTHMORE COLLEGE,
SWARTHMORE, PA. (M. McC. M.)

[2] Some measurements of the Transmission of Ultraviolet Radiation through Various Fabrics, W. W. Coblentz, R. Stair, C. W. Schoffstall; B.S.J.R., *1*, p. 105; 1928.

An Announcement:

THE REVIEW OF SCIENTIFIC INSTRUMENTS

The Journal of the Optical Society of America was established in 1917. Publication was interrupted during the war, so that by the end of 1919 only six numbers had been issued. These constitute vols. I-III. In 1920, publication was resumed on a regular schedule, six numbers per year. This continued through 1921, these two years comprising volumes IV and V.

Beginning with 1922 the Journal was enlarged by the addition of a section on scientific instruments and the name was changed to "The Journal of the Optical Society of America and Review of Scientific Instruments." This enlargement, which was partly in the nature of an experiment, was made at the suggestion of the National Research Council and with the cooperation and assistance of the Scientific Apparatus Makers of America.

The experience of the past seven years seems to have demonstrated conclusively that there is a place in America for an independent journal, devoted to scientific instruments and of a type similar to the section on scientific instruments in the Journal of the Optical Society of America and Review of Scientific Instruments. Accordingly, beginning with January, 1930, the Optical Society, with the continued cooperation of the Scientific Apparatus Makers of America, will publish two separate journals:

(1) THE JOURNAL OF THE OPTICAL SOCIETY OF AMERICA, devoted primarily to articles on all branches of pure and applied optics—physical optics, physiological optics, geometrical optics, etc.; and

(2) THE REVIEW OF SCIENTIFIC INSTRUMENTS, containing original articles and abstracts on instruments and methods—thermal, mechanical, electrical, as well as optical—for all kinds of research and testing in university, governmental and industrial laboratories, and wherever scientific instruments are used. Both journals will be under the same editorial control as at present. Each journal will be issued twelve times per year.

Members of the Optical Society of America will receive both journals. The subscription rate for *both* journals is five dollars per year; each journal separately, four dollars per year.

The editors wish to take this occasion to thank authors, advertisers and all others who have collaborated in making this Journal possible; and further to solicit continued support for these two separate journals. In particular, manuscripts for publication will be welcome irrespective of whether authors are members of the Optical Society or not. New instruments, or modification of older ones, new methods of research and testing, new laboratory or lecture experiments, are constantly being developed in the laboratories of America. Tell your colleagues about them through the pages of the Review of Scientific Instruments.

F.K.R.

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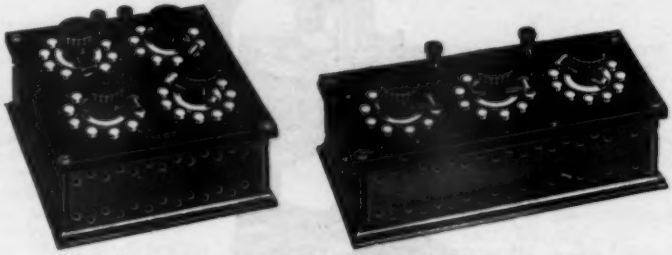

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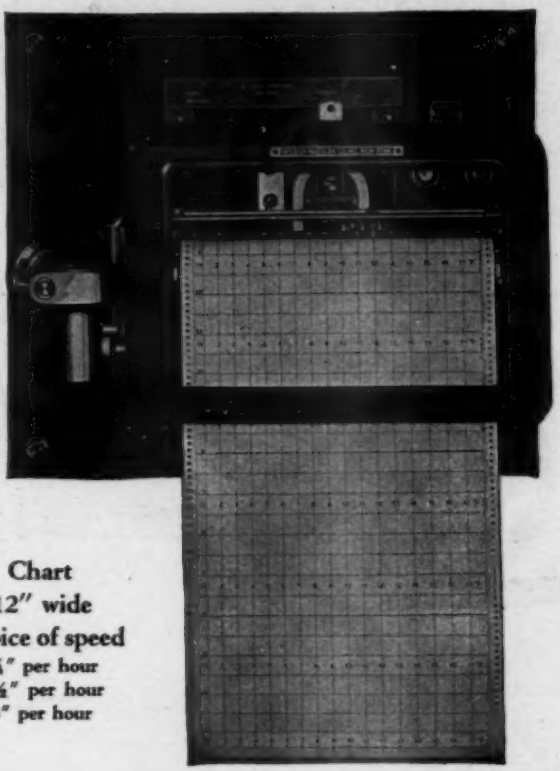

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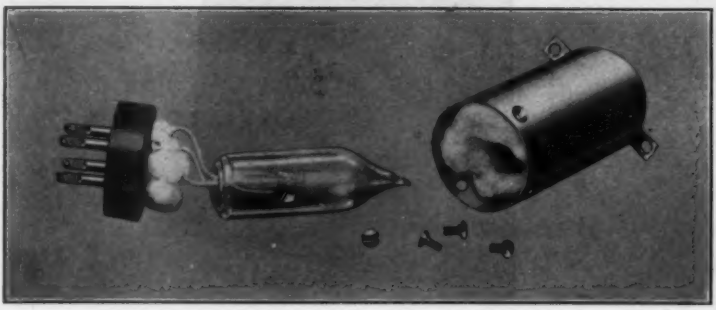

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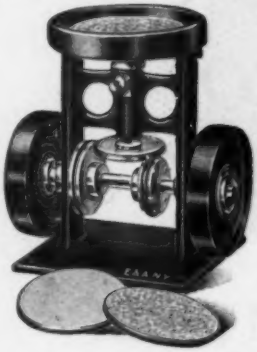

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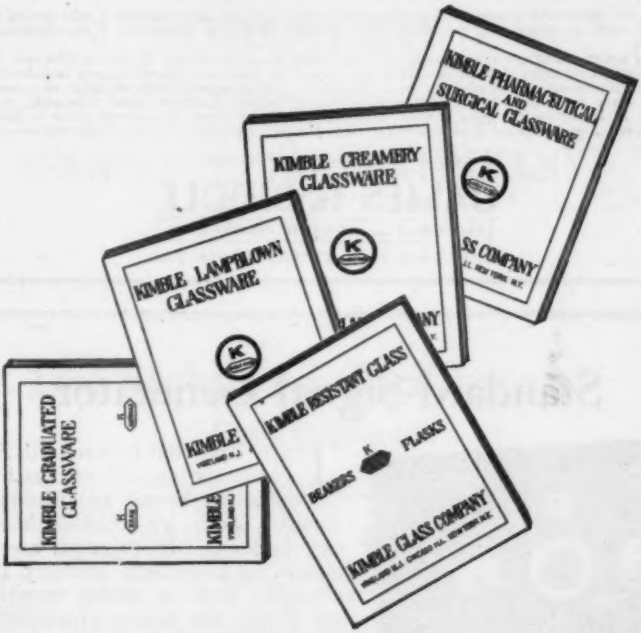

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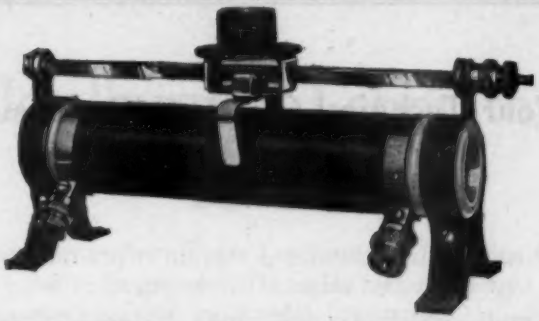

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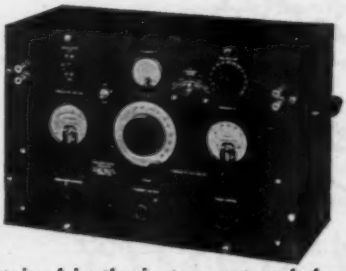

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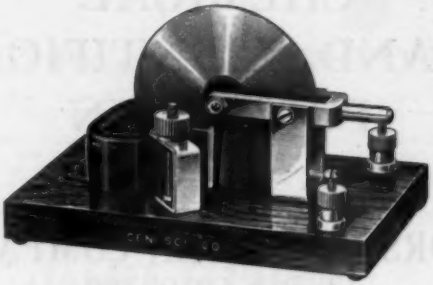

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(3) EXPOSITION. Articles will also be judged on clearness, conciseness, and general arrangement of material. Special attention will be paid to diagrams. While brevity is a virtue in scientific writing, brevity ceases to be a virtue when it is carried to the point of introducing obscurity or of omitting essential details.

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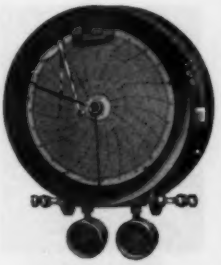

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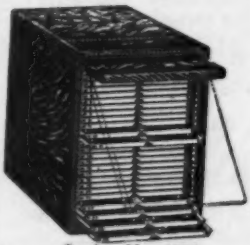

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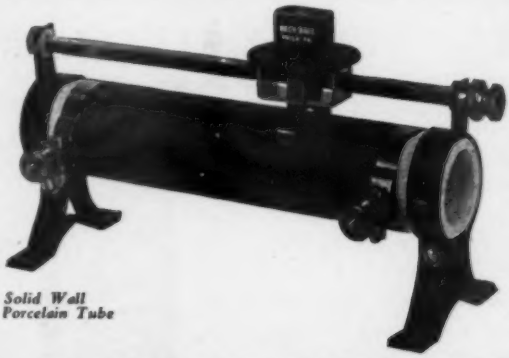

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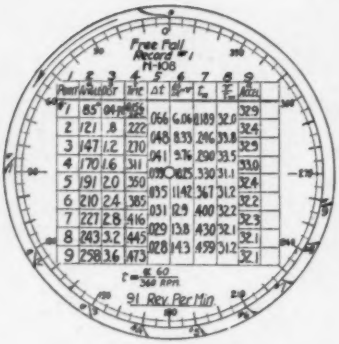

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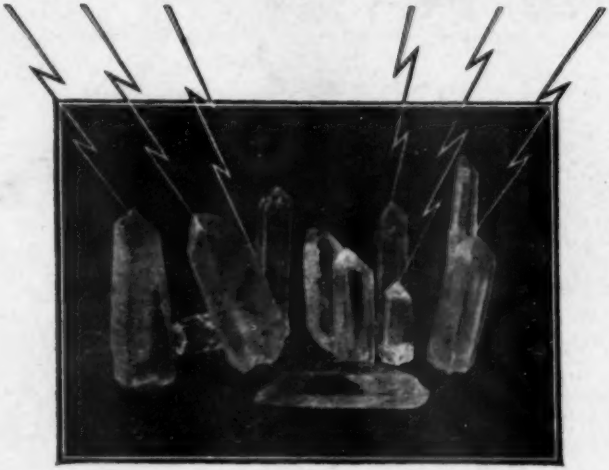

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